Bulletin of the Seismological Society of America, Vol. 85, No. 4, pp. 963–985, August 1995

The Origin of Crowley's Ridge, Northeastern Arkansas: Erosional Remnant or Tectonic Uplift?

by Roy B. Van Arsdale, Robert A. Williams, Eugene S. Schweig, Kaye M. Shedlock, Jack K. Odum, and Kenneth W. King

Abstract The geomorphology of Crowley's Ridge, apparent Quaternary reactivation of the ridge-bounding faults, and orientation of the faults to the present stress field suggest that the faults bounding Crowley's Ridge and the western margin of the Reelfoot rift may be seismogenic.

Fifteen high-resolution seismic reflection lines were acquired across and adjacent to the margins of Crowley's Ridge to test the hypothesis that Crowley's Ridge is fault bounded. Eleven of the reflection lines were 24-channel Mini-Sosie data with 1-sec record length and four lines were 24-channel shotgun-source data with 0.25-sec record length. Nine lines traversed the margins and adjacent areas of the northern segment of the ridge near Jonesboro, Arkansas, and the other six were located south of Jonesboro on the southern segment. The reflection data show that Paleozoic through Eocene Wilcox sections have been uplifted beneath Crowley's Ridge from 60 to 30 m across ridge-bounding faults. However, Eocene or Pliocene–Pleistocene near-surface strata appear to be displaced a maximum of 7.5 m. Based on reflection and geomorphologic data, we believe that reactivation of the bounding faults of Crowley's Ridge occurred concurrently with and strongly influenced Wisconsin denudation of the Mississippi valley.

Introduction

Crowley's Ridge, in northeastern Arkansas (Fig. 1), has been interpreted to be an erosional remnant formed during Quaternary incision of the ancestral Mississippi River flowing west of the ridge and the ancestral Ohio River flowing east of the ridge (Call, 1891; Fisk, 1944; Guccione *et al.*, 1986, 1990). However, the Reelfoot rift AR-6 COCORP seismic reflection line (Nelson and Zhang, 1991) identified a down-to-the-west fault beneath the western side of the southern segment of the ridge, thus suggesting that Crowley's Ridge may be tectonic in origin. Five preliminary Mini-Sosie shallow seismic reflection lines revealed displaced Cretaceous and Tertiary strata beneath the remaining margins of the ridge to within 0.2 sec (approximately 200 m) of the ground surface (Van Arsdale *et al.*, 1992, 1994). Based on the preliminary data, six additional Mini-Sosie surveys were conducted to confirm the original data and to establish the strike of the proposed ridge-bounding faults. In addition, four shotgun-source seismic reflection surveys were conducted to image the uppermost 0.25 sec to determine if the faults identified in the Mini-Sosie data displace Quaternary strata in the upper 200 m.

Geologic Setting

Crowley's Ridge is a topographic ridge that extends 320 km from Helena, Arkansas, to Thebes, Illinois. In Arkansas, the ridge is from 1.6- to 19-km wide, averages 60 m above the adjacent lowlands, and is stratigraphically composed of Eocene and Pliocene–Pleistocene unconsolidated sediments (Fig. 2). The Eocene sequence is dominated by continental and deltaic sands and clays with minor intervals of lignite (Murray, 1961). Eocene units dip approximately 0.5° southeast (Meissner, 1984) and are unconformably overlain by a Pliocene–Pleistocene upland complex (also locally called the Lafayette Gravel or Citronelle Formation) of fluvial sand, gravel, and minor clay locally exceeding 50 m in thickness (Autin *et al.*, 1991). Above these fluvial deposits, up to 10 m of Pleistocene loess is locally preserved with major accumulations confined to the southern portion of Crowley's Ridge (Saucier, 1974; Guccione *et al.*, 1986). Flanking the ridge at our reflection-line sites are Early Wisconsin (Saucier, 1974; Royall *et al.*, 1991; Autin *et al.*, 1991) or Illinoian (Rutledge *et al.*, 1990) stream terraces underlain by glacial outwash deposited by braided streams (valley train deposits of Saucier and Snead, 1989). The terraces are locally capped by loess, the youngest being the Peoria loess radiocarbon dated at 17,850 to 21,270 yr old (Rutledge *et al.*, 1990; Autin *et al.*, 1991).

Crowley's Ridge lies within the northwestern portion of the Mississippi embayment. The Mississippi embayment is a broad and gentle south-southwest-plunging syncline of

Cretaceous and Tertiary age (Stearns, 1957) that overlies the currently seismically active late Precambrian Reelfoot rift (Figs. 1 and 3) (Ervin and McGinnis, 1975; Hildenbrand, 1985).

Seismicity and Neotectonics of Crowley's Ridge and Vicinity

Current seismicity in the Mississippi embayment occurs primarily east of Crowley's Ridge and is coincident with structural highs within the Reelfoot rift (Fig. 3). Specifically, the northeast-trending Blytheville arch and the northwest-trending Lake County uplift (zone of dense epicenters) are the most seismically active areas in the embayment (Russ, 1982; Hamilton and Zoback, 1982; Hamilton and McKeown, 1988; Chiu *et al.,* 1992).

Crowley's Ridge overlies and crosses the western margin of the Reelfoot rift near Jonesboro, Arkansas (Fig. 3). The intersection area of the ridge and rift margin also coincides with the Jonesboro pluton, the change from the N30°E-trending northern ridge segment to the N5°E-trending southern ridge segment, and a proposed northwest-trending fault line (Fisk, 1944; Cox, 1988a, b; Van Arsdale *et al.,* 1992; 1994). Seismicity northeast of the ridge from near New Madrid to Charleston, Missouri, may be associated with the west-bounding faults of the Reelfoot rift (Hamilton and Zoback, 1982; Howe, 1985; Van Arsdale *et al.,* 1992) (Fig. 3).

The pronounced linearity, steepness of its margins, and the fact that Crowley's Ridge is the largest ridge in the Mississippi valley suggest that the ridge may be fault bounded

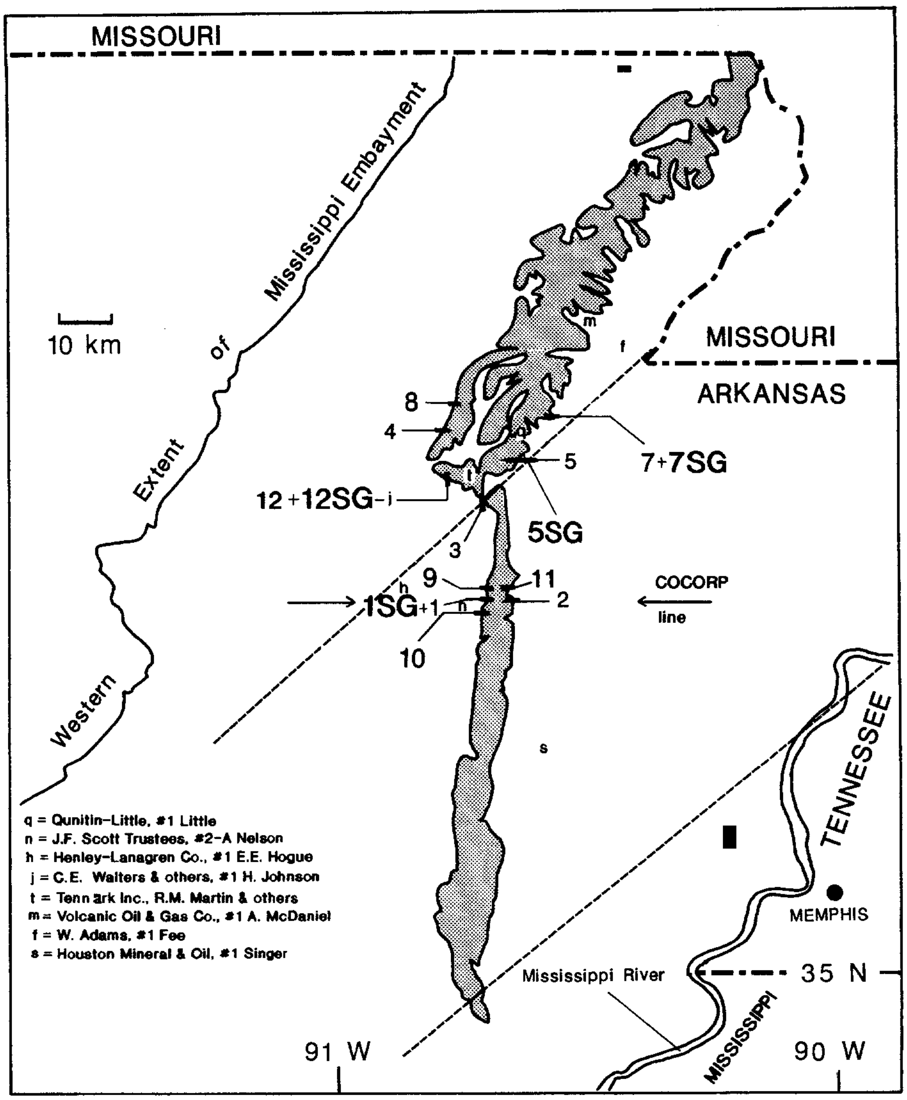

Figure 1. Northeastern Arkansas segment of Crowley's Ridge. Numbers 1 through 5 indicate 1990 Mini-Sosie seismic reflection line locations, numbers 7 through 12 are 1991 Mini-Sosie line locations, and SG indicates 1991 shotgun source line locations. Lowercase letters mark well locations and the dashed lines are the Reelfoot rift boundaries. Arrows locate where the AR-6 COCORP seismic reflection line crossed Crowley's Ridge (Nelson and Zhang, 1991).

along its entire length (Cox, 1988a, b; Van Arsdale *et al.*, 1992, 1994; Fischer and Schumm, 1993). Nelson and Harrison (1993) mapped faults in Crowley's Ridge at Thebes Gap, Missouri, that displace Pliocene–Pleistocene Mounds (upland complex) gravel. Thus, there are preliminary geophysical, geomorphic, and bedrock structure data to support Quaternary faulting along the margins of Crowley's Ridge.

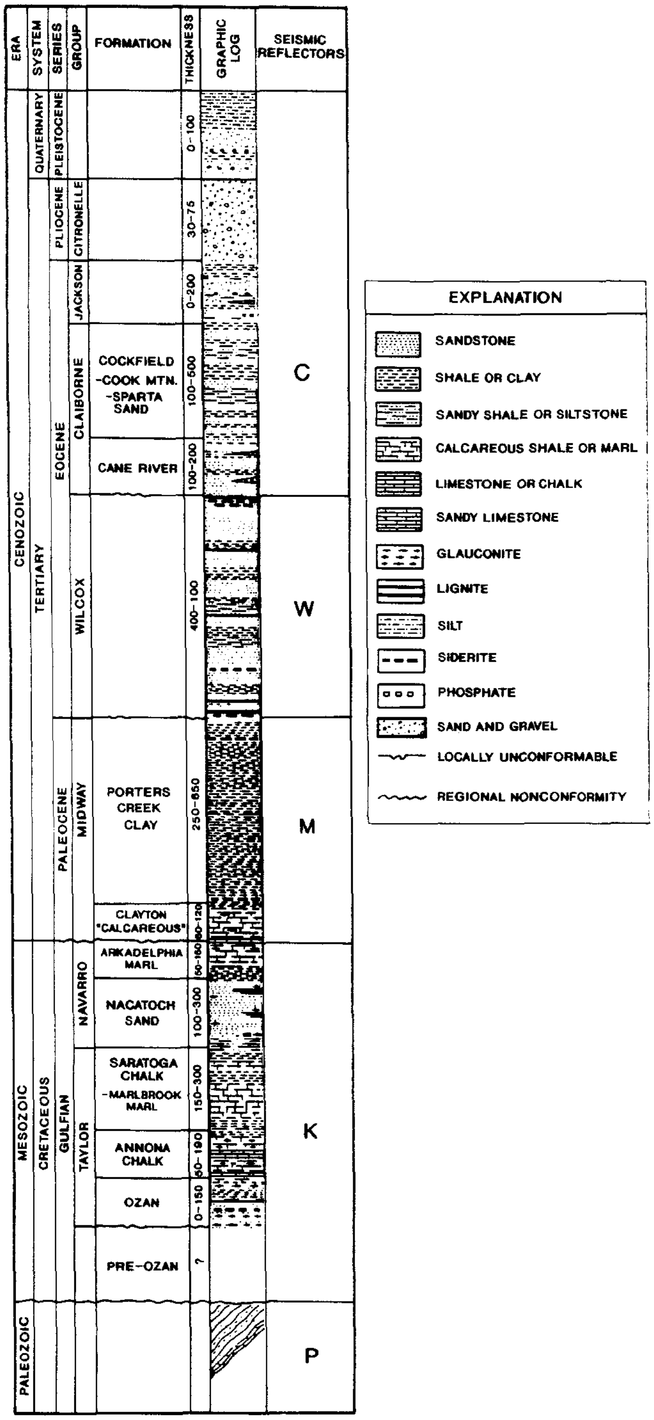

Figure 2. Cretaceous–Quaternary stratigraphic section for northeast Arkansas with principal seismic reflectors: P = Paleozoic, K = Cretaceous, M = Midway Group, W = Wilcox Group, and C = Claiborne Group (modified from Renfroe, 1949).

Data Acquisition and Processing

Eleven Mini-Sosie (Barbier et al., 1976) and four shotgun-source seismic reflection profiles were recorded across or adjacent to five different margins of Crowley's Ridge (Fig. 1). The field data were acquired using common-midpoint seismic reflection techniques (Mayne, 1962) and line lengths varied from 0.3 to 5 km. Acquisition parameters and seismic processing techniques are listed in Table 1.

We acquired all reflection data using an end-on source-receiver geometry. Source and geophone spacing for the Mini-Sosie system was selected to image the upper 1 sec of two-way travel time (approximately 1.2 km) so that the Cretaceous through Tertiary section would be recorded. In most of the lines, the top of the Paleozoic was also clearly imaged. This configuration allowed determination of displacement at the top of the Cretaceous and imaging of reflectors to as shallow as 0.20 sec (approximately 200 m). Source and geophone spacing for the shotgun system was selected to image the upper 0.20 sec of two-way travel time. Reflection times were converted to depths using interval velocities derived

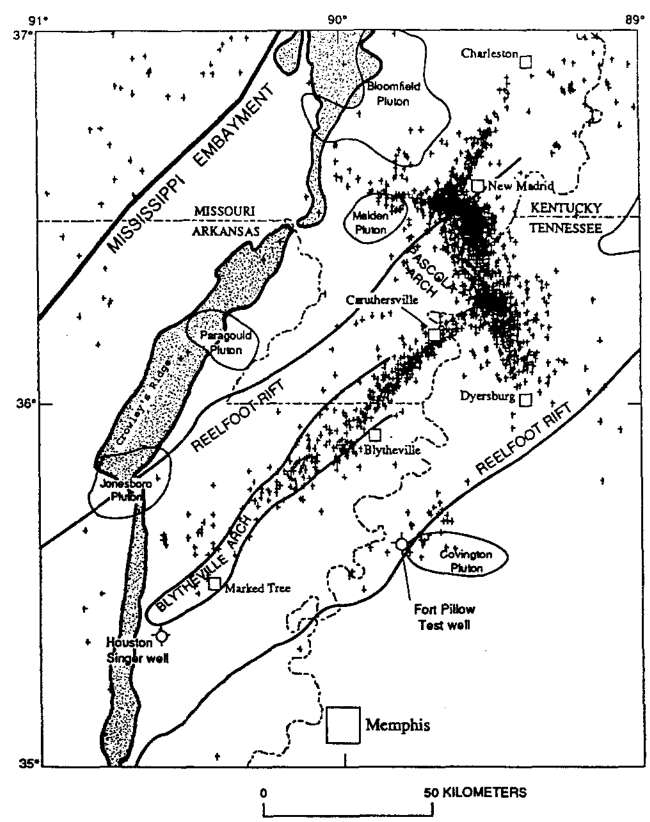

Figure 3. Map showing Crowley's Ridge and epicenters of microearthquakes (+) in the upper Mississippi embayment (modified from Luzietti *et al.*, 1992).

from stacking velocities. Because the level of data quality is generally only fair to good we could not determine an accurate stacking velocity to less than about ± 10%. Therefore, the reflector depths determined from these data are also approximate.

The stratigraphy of the area is detailed in Figure 2. Stratigraphy of the Mini-Sosie lines was interpreted using petroleum test wells located on or near Crowley's Ridge (Fig. 1) (Renfroe, 1949; Dart, 1990). Additional data used in interpreting the seismic lines include the New Madrid test well-1-X in New Madrid County, Missouri (Crone, 1981; Frederiksen *et al.,* 1982), the Fort Pillow test well in Lauderdale County, Tennessee (Moore and Brown, 1969), and published seismic lines that pass over (Nelson and Zhang, 1991) or near Crowley's Ridge (Hamilton and Zoback, 1982; Howe and Thompson, 1984; Howe, 1985; Luzietti *et al.,* 1992). The subsea elevation of tops of the Paleocene–Eocene Wilcox Group, Paleocene Midway Group, Cretaceous section, and Paleozoic section (Table 2) have been picked from the Tennark well (Renfroe, 1949) located southwest of Jonesboro near the middle of our seismic lines. Strong reflectors exist at or near the tops of these stratigraphic units in all of the seismic lines on the northern ridge segment (Table 2). The same reflectors are readily identified on the southern ridge segment lines but the elevations of these stratigraphic units are lower because they are located within the Reelfoot rift (Fig. 1).

Geologic interpretation of the shotgun lines was based on the above data plus lignite test wells (Holbrook, 1980; Meissner, 1984) and unpublished water well logs provided by the Arkansas Geological Commission. The base of the Pliocene–Pleistocene section is readily picked in the wells because it consists of gravel that overlies Eocene Wilcox and Claiborne group sands and clays. Thickness of the Pliocene–Pleistocene section in the study area varies from 24 to 70 m.

Interpretation of Mini-Sosie and Shotgun Reflection Lines

Seismic reflections of the geologic units identified in the Mini-Sosie lines are consistent. With our acquisition parameters the Claiborne Group is characterized by discontinuous reflections, the Wilcox Group by continuous reflections, the Midway Group by almost no reflections, the Cretaceous section by continuous reflections, and the Paleozoic section changes from discontinuous reflections at the top to no reflections with depth.

Table 1
Data Acquisition and Processing Parameters

	Acquisition Style	
	Sosie Process	Traditional
Source type	3 earth tampers (wackers)	12-gauge shotgun
Source array	3-m spacing parallel to profile line	single shot on station
Impacts per station	2000	single 1-oz. slug
Source point interval	15.2 m (50 ft)	2.44 m (8 ft)
Geophone array	12, 28-Hz geophones, clustered	single, 100-Hz geophone
Geophone interval	15.2 m	2.44 m
Recording geometry	24 channels, in-line, off-end:	same
	ch 1: 46- to 61-m offset	4.9-m offset
Recording passband	20–240 Hz, 60-Hz notch	180–1000 Hz
Recording system	I/O DHR-2400	same
Sampling interval	1.0 msec	0.25 msec
Record length	1000 msec	250 msec
Recording format	SEG-Y, magnetic tape	same

Data Processing Sequence
1. Trace edit.
2. Common midpoint (CMP) sort.
3. Elevation static timing corrections (correction velocity: 1400 m/sec).
4. Remove ground-roll and first-arrival (refractions) phases by mute.
5. Normal-moveout velocity correction (0.55–1.6 km/sec, shotgun data; 1.4–2.2 km/sec, Sosie data).
6. Bandpass frequency filter (roughly: 80–100–350–400 Hz, shotgun; 20–30–120–150 Hz, Sosie).
7. Surface consistent residual statics (maximum shift: 0.005 sec, shotgun; 0.015 sec, Sosie).
8. CMP stack (nominally 12-fold).
9. Frequency-wavenumber (FK) filter to remove residual ground-roll noise.
10. Predictive deconvolution filter (prediction distance: 2nd zero, operator length 0.005–0.1 sec).
11. Bandpass frequency filter (roughly 35–45–120–150 Hz, Sosie, 80–100–350–400 Hz, shotgun).
12. Automatic gain control (amplitude scaling window 0.1–0.6 sec).

Migration of the shotgun and Sosie data generally degraded data quality and is not shown here.

Faulting beneath the Western Margin of the Southern Ridge Segment

Lines 1, 9, 10, and 1SG cross the western margin of the southern ridge segment (Figs. 1 and 4 through 7), which is approximately 30-m high at this location. Line 1 coincides with a portion of the Reelfoot rift COCORP AR-6 line. Although resolution of the top of the Paleozoic is poor in line 1, it is clearly identifiable in lines 9 and 10. Depths of the top of the Paleozoic vary from 0.7 to 0.83 sec, which is in good agreement with a time of 0.8 sec picked on the COCORP line (Nelson and Zhang, 1991).

The Nelson number 2 well is believed to have been drilled near the western end of lines 1, 9, and 10 (Fig. 1 and Table 2). Depth to the top of the Paleozoic rocks estimated from the seismic data is approximately 230 m deeper than the depth obtained from the Nelson number 2 well. However, this well was drilled in 1921 and its exact location is not known. If the Nelson number 2 well is indeed near the western end of these lines, then our calculated depths would be too deep for the lines or, alternatively, there may be a down-to-the-east fault between the well and the seismic lines.

Down-to-the-west faulting is clearly evident in Mini-Sosie lines 1, 9, and 10 with the major fault that cuts highest in the section probably being the same on each of the lines (Figs. 4-6). The major fault is located directly beneath the topographic base of Crowley's Ridge on all three Mini-Sosie lines and appears to correspond with the fault identified on the COCORP line. The strike of this major fault parallels the ridge margin, thus confirming that the topographic margin of Crowley's Ridge is coincident with an underlying bedrock fault. The top of the Paleozoic and Cretaceous sections are displaced by a series of faults approximately 0.07 sec (67 m) in lines 9 and 10 and by a single fault with 0.04 sec of displacement (42 m) in line 1. Individual faults at STAT 620 of line 9 and STAT 750 of line 10 abruptly displace the Paleozoic reflection by up to 0.025 sec (26 m) over a horizontal distance of about 40 m. Changes in two-way travel time due to velocity and elevation variations are 0.0 to 0.003 sec across these faults and cannot account for the observed displacements on these reflectors. As is evident from these figures, the quality of line 1 and the seismic velocity control are not as good as the data of lines 9 and 10, and so we believe that the estimate of 0.07 sec (67 m) of fault displacement beneath this ridge margin is more accurate. These Mini-Sosie lines also reveal that the faulting continues through the Paleocene Midway and apparently to the top of the Eocene Wilcox to within 0.20 sec (160 m) of the ground surface.

Line 1SG (Fig. 7) was acquired over the fault identified in Mini-Sosie line 1 in order to image the uppermost 0.25 sec. We interpret 0.03 sec (7 to 8 m) of down-to-the-west displacement of Eocene reflectors (highlighted in Fig. 7) between STAT 188 and 139. Lack of surface strata exposure prevented us from determining if any faults cut Quaternary sediments.

Table 2
Subsea Elevations of Geologic Units, in Meters*

Sosie Line or Well	Top of Wilcox G.	Top of Midway G.	Top of Cretaceous	Top of Paleozoic
1	−180	−231	−685	−823
2	−142	−206	−601	−778
3	−85	−156	−368	−508
4		−8	−268	−375
5	−30	−75	−297	−410
t	−30	−98	−262	−404
q			−276	−421
n				−594

*t = Tennark Inc./R. M. Martin & others; q = Quintin-Little/#1 Little; n = J. F. Scott Trustees/#2-A Nelson; and G = Group.

Structures beneath the Eastern Margin of the Southern Ridge Segment

Lines 2 and 11 descend eastward off Crowley's Ridge, which is 30-m high at this location (Figs. 1, 8, and 9). Like line 1, line 2 is coincident with a portion of the Reelfoot rift COCORP line AR-6 (Nelson and Zhang, 1991). The top of the Paleozoic is at 0.77 sec in the eastern end of lines 2 and 11 and approximately 0.8 sec in the COCORP line. No faulting was interpreted by Nelson and Zhang (1991) beneath the eastern margin of the ridge but inspection of their data does suggest that the reflectors have been disrupted. The top and base of the Wilcox and Cretaceous sections are well imaged over most of line 2. From STAT 345 to 375 the Paleozoic through Eocene Wilcox formations have been folded and faulted into a horst with approximately 0.025 sec (38 m) of structural relief at the top of the Cretaceous. This structure appears to persist through to the top of the Wilcox. On the east side of the horst at STAT 375, a steep fault displaces the Wilcox 0.02 sec (24 m). On the west side of the horst, a steep fault is interpreted at STAT 355, primarily on the evidence of the upturned Wilcox reflectors east of the fault and the upturned Cretaceous reflectors on the west side of the fault. The elevations of the mapped units are the same at the eastern and western ends of line 2.

Line 11 reveals flat-lying strata beneath the ridge and easterly dipping strata beneath the ridge margin (Fig. 9). All of the stratigraphic units are about 0.04 sec (50 m) higher under the ridge. A horst with 0.01 sec (12 m) of structural relief at the top of the Cretaceous is evident beneath the ridge margin. Slight folding in the overlying Wilcox section suggests that fault reactivation occurred after Wilcox (Eocene) deposition. This horst is probably the same structure as identified in line 2. Thus, the eastern side of the southern ridge margin is underlain by faults between lines 2 and 11.

Faulting beneath the Southwest Termination of the Northern Ridge Segment

Lines 3, 12, and 12SG are oriented north to south and were located across the southwest termination of the north-

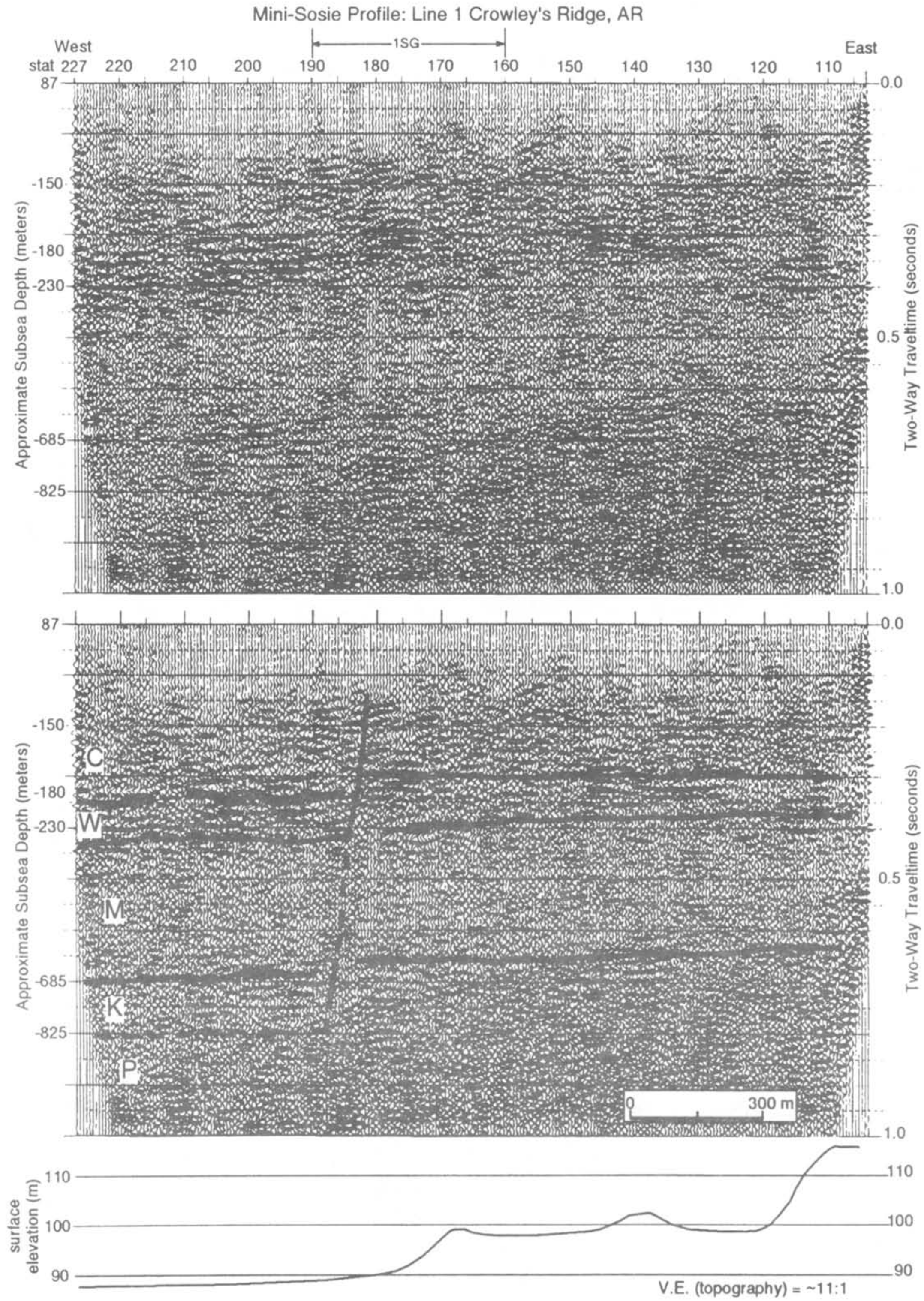

Figure 4. Mini-Sosie reflection line 1 and geologic interpretation. See Figure 1 for location. The line is 1.8-km long. P = Paleozoic, K = Cretaceous, M = Midway Group, W = Wilcox Group, and C = Claiborne Group.

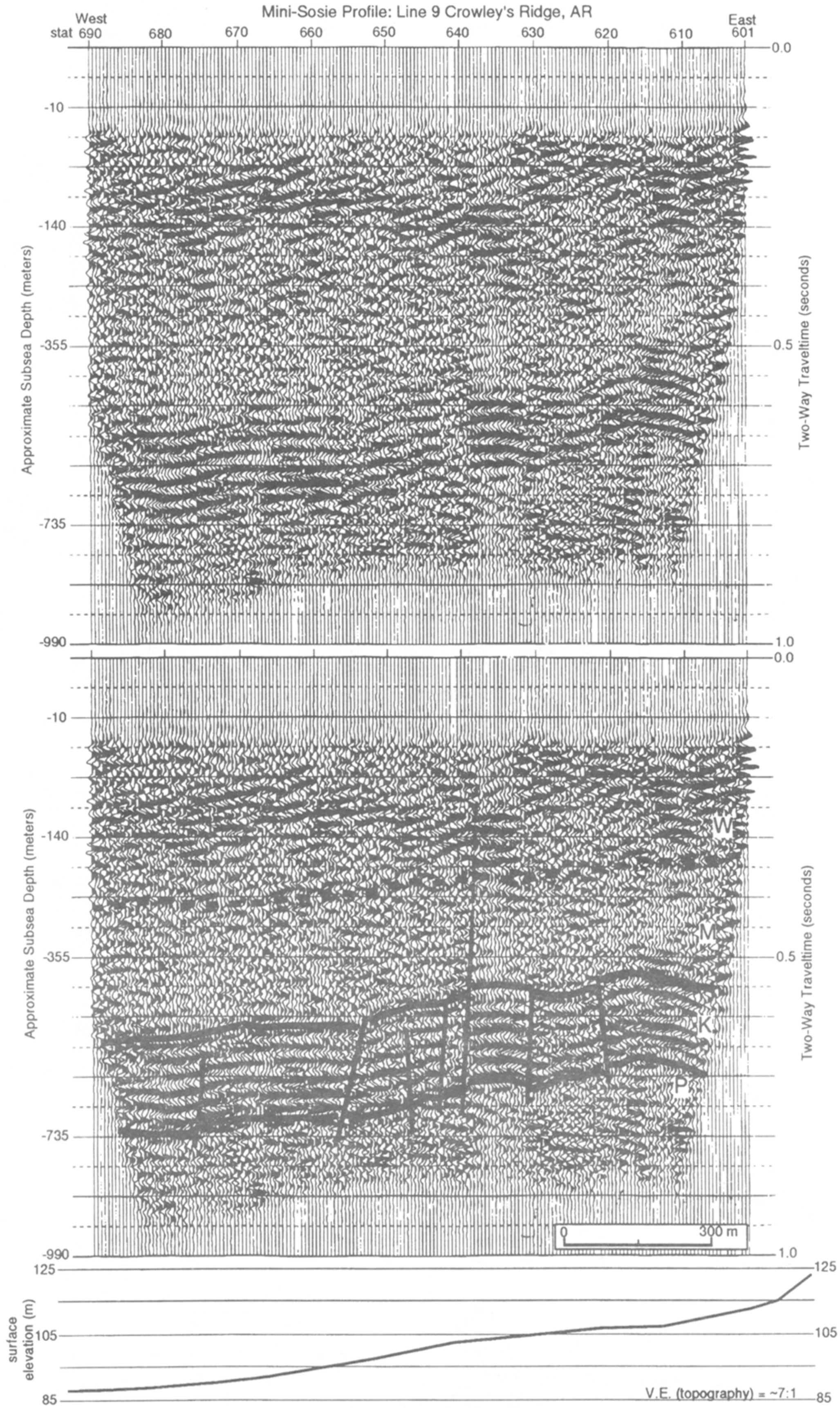

Figure 5. Mini-Sosie reflection line 9 and geologic interpretation. See Figure 1 for location. The line is 1.4-km long. P = Paleozoic, K = Cretaceous, M = Midway Group, and W = Wilcox Group.

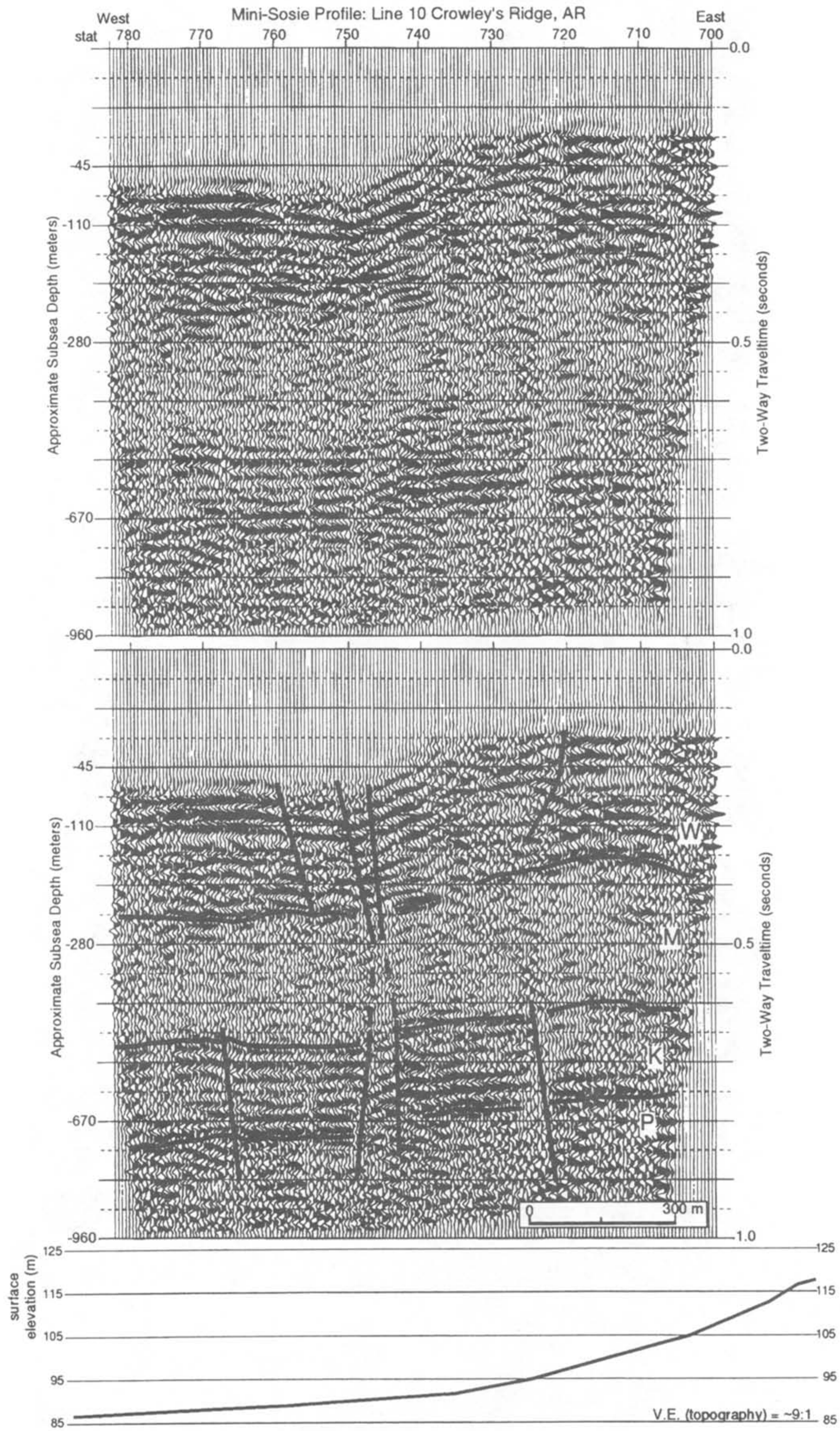

Figure 6. Mini-Sosie reflection line 10 and geologic interpretation. See Figure 1 for location. The line is 1.2-km long. P = Paleozoic, K = Cretaceous, M = Midway Group, and W = Wilcox Group.

ern ridge segment where the ridge is approximately 40-m high (Figs. 1 and 10 through 12). A data gap exists between STATs 565 and 575 of line 3 where the line crosses a highway.

The Tennark well (Fig. 1) is located on top of the 40-m high ridge 3.2 km north of line 3. Comparison of elevations of the stratigraphic units reveals that the Paleozoic and Cretaceous tops are about 100 m higher and the Midway and Wilcox tops are about 50 m higher in the Tennark well located on top of the ridge than in the southern end of line 3, which is south of the ridge (Table 2). The data in Table 2 also reveal that the Midway Group is approximately 50 m thicker in line 3 than in the Tennark well.

Very few reflectors were imaged beneath the ridge in line 3 from STAT 503 to 600; however, reflection characteristics from 0.1 to 0.15 sec are similar to the Claiborne in the southern portion of the line. Although reflection continuity is poor, it does appear that the upper 0.15 sec of reflectors dip north from STAT 600 to 580. Reflectors south of the ridge are continuous and identifiable. From STAT 600 to 635 the reflectors dip southerly, descending 0.02 sec (16 m) and from STAT 635 to the southern end of the line they are horizontal. The upturned and apparently truncated reflectors suggest a fault lies beneath STAT 600 of line 3 at the base of Crowley's Ridge.

As in line 3, the data quality in line 12 is poor; however, a few strong and continuous reflectors, interpreted to be the top of the Cretaceous section, can be traced beneath Crowley's Ridge (Figs. 1 and 11). The Cretaceous appears to be displaced at STATs 860 and 845 of line 12 a total of 0.05 sec (55 m) down to the south. We postulate the fault zone in line 3 is the same as the faults in line 12, and thus the southwestern margin of the northern ridge segment is underlain by a down-to-the-southwest fault zone.

Line 12SG is located at the base of the ridge over the northern fault of line 12 (Figs. 1 and 12). The quality of line 12SG is poor, but there are reflections on the north end of this line that terminate abruptly near STAT 165. These reflectors are less than 0.04-sec (10 m) deep and are probably Eocene strata that may have been truncated by faulting. Absence of surface dissection did not allow us to determine if Quaternary sediments have been faulted.

Eastern Margin Structures of the Northern Ridge Segment

Line 5 is a 5-km-long line located on the east side of the northern segment of Crowley's Ridge (Figs. 1 and 13). The data gap between STATs 225 and 235 is where a highway and railroad track were crossed. The relief of the ridge is only 15 m in this area. The western portion of the profile was shot along a gravel road that followed a stream valley, so there is no sharp topographic break at the ridge margin at STAT 240. The Quinten Little well is located approximately 2.5 km north of the western end of line 5 and the Tennark well is located approximately 15 km southwest of line 5 (Fig. 1). As illustrated in Table 2, the elevations of the tops of the stratigraphic units in the wells are reasonably close to the calculated depths in line 5. However, we are uncertain whether the uppermost picked reflector is truly the

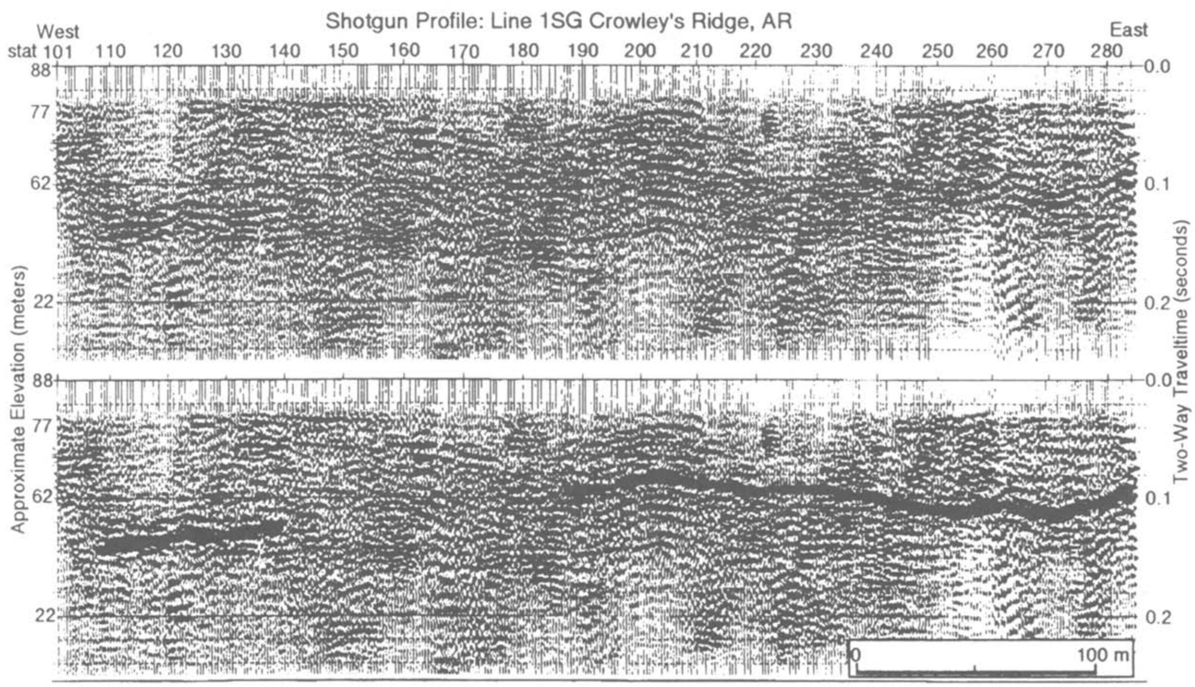

Figure 7. Shotgun is reflection profile 1SG and geologic interpretation. See Figure 1 for location. This line 446-m long and was shot from STAT 160 to 190 on Mini-Sosie line 1 (Fig. 4). The highlighted reflector is probably within the Eocene section.

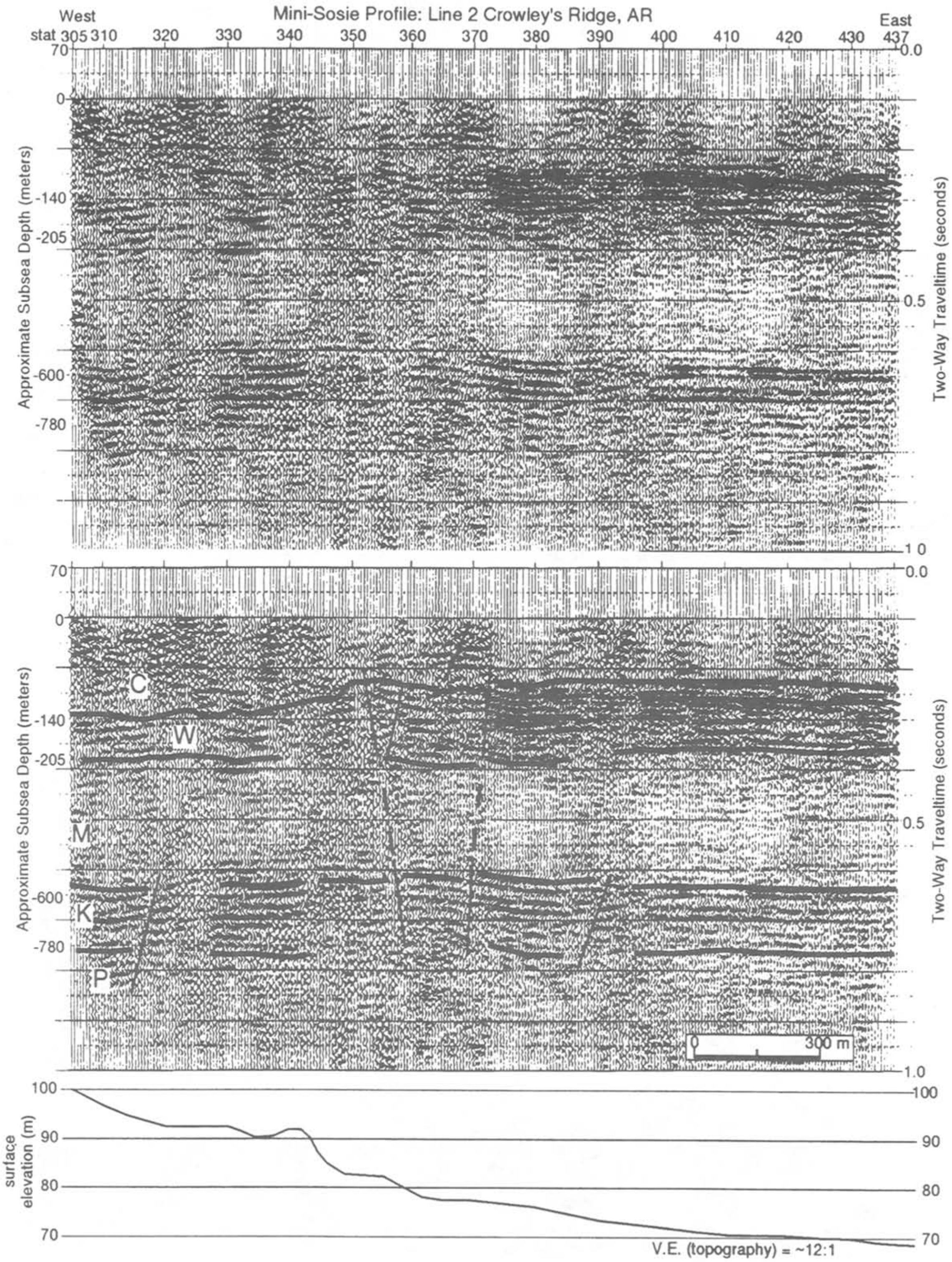

Figure 8. Mini-Sosie reflection line 2 and geologic interpretation. See Figure 1 for location. The line is 2.0-km long. P = Paleozoic, K = Cretaceous, M = Midway Group, W = Wilcox Group, and C = Claiborne Group.

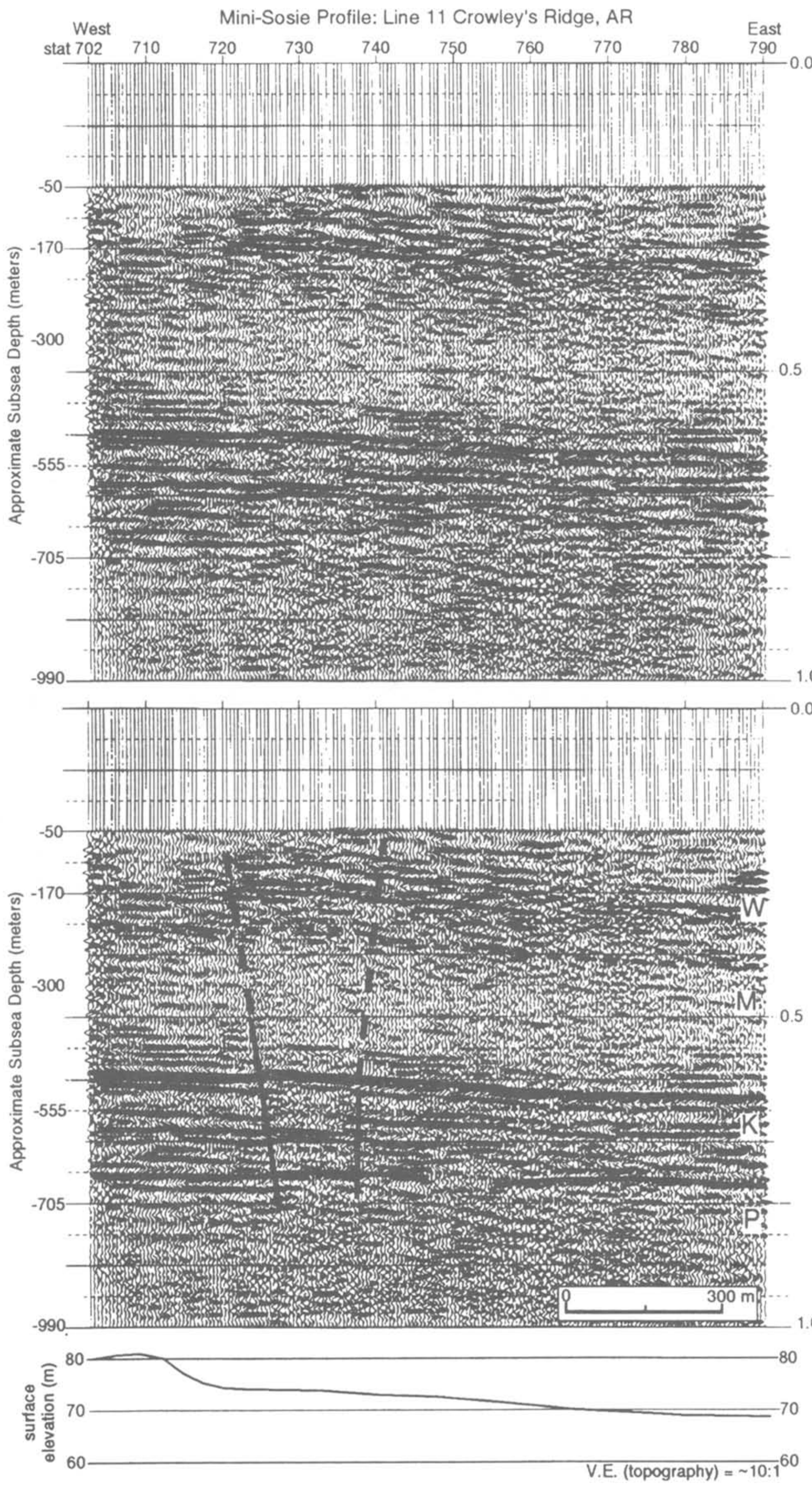

Figure 9. Mini-Sosie reflection line 11 and geologic interpretation. See Figure 1 for location. The line is 1.3-km long. P = Paleozoic, K = Cretaceous, M = Midway Group, and W = Wilcox Group.

top of the Wilcox or just a strong reflector near the top of the Wilcox.

From STAT 125 to 185, a broad anticline with 0.02 sec (25 m) of amplitude is present in the Paleozoic and Cretaceous sections. The fold cannot be identified in the Midway Group, but a much shorter wavelength fold with 0.02 sec (14 m) of amplitude occurs in the Wilcox and possibly Claiborne from STAT 150 to 175. When reflectors are projected into the data gap at STAT 230 from the east and west, there appears to be a down-to-the-east fault or fold. This proposed fault/fold lies beneath the ridge margin. A small horst with 0.01 sec (9 m) of displacement is present between STATs 330 and 345. The west-bounding fault of the horst appears to fold strata as stratigraphically high as the top of the Wilcox.

A graben is clearly evident at the level of the Paleozoic and Cretaceous sections between STATs 380 and 415. The west-bounding fault of the graben displaces the Paleozoic

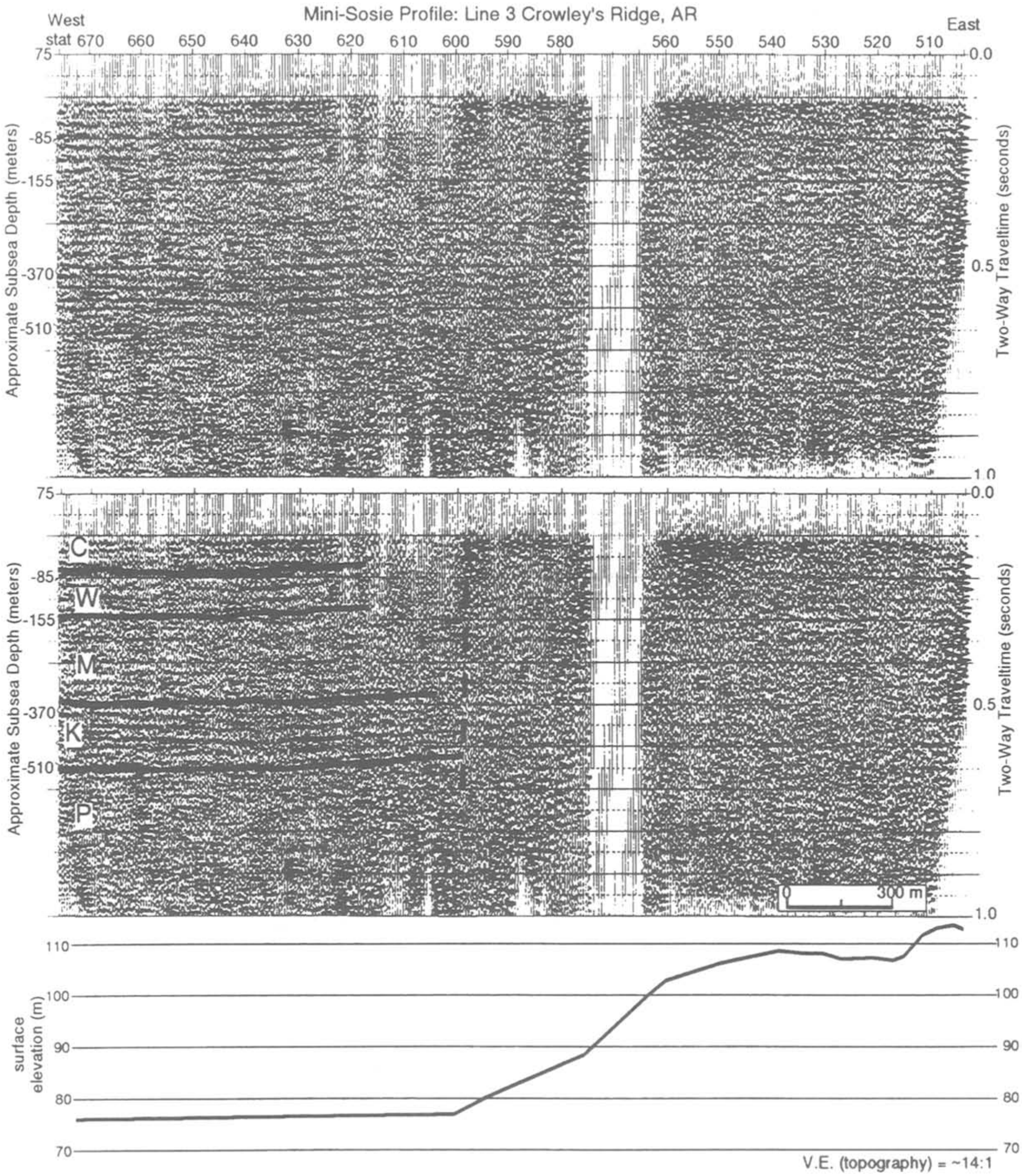

Figure 10. Mini-Sosie reflection line 3 and geologic interpretation. See Figure 1 for location. The line is 2.6-km long. P = Paleozoic, K = Cretaceous, M = Midway Group, W = Wilcox Group, and C = Claiborne Group.

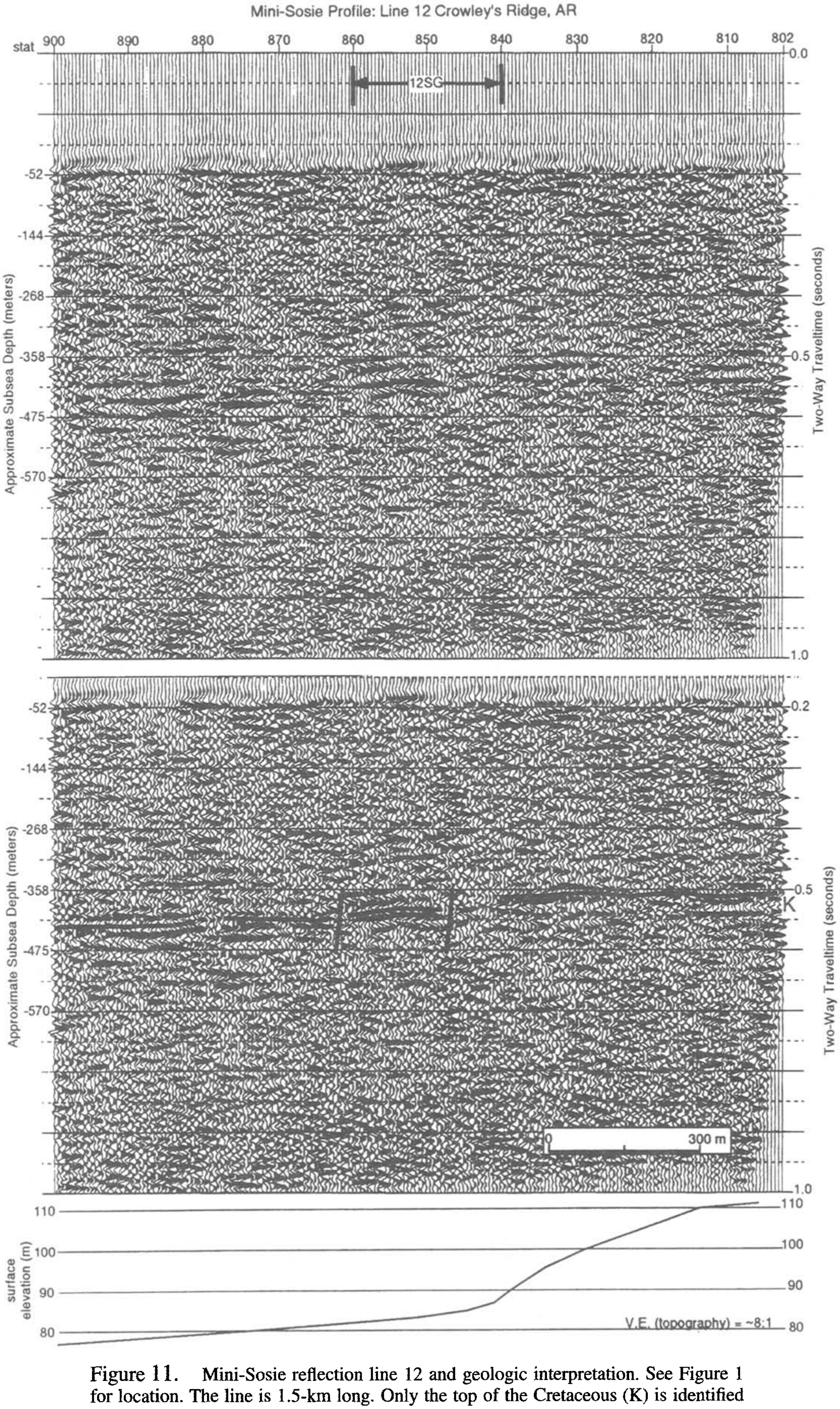

Figure 11. Mini-Sosie reflection line 12 and geologic interpretation. See Figure 1 for location. The line is 1.5-km long. Only the top of the Cretaceous (K) is identified in this profile.

and Cretaceous sections 0.07 sec (90 m). Normal fault displacement of 0.035 sec (28 m) at the base of the Wilcox and thickening of the Wilcox indicates that the fault was active during basal Wilcox deposition. The fault can be traced to the top of the Wilcox, where it appears that there has been reverse movement after Wilcox deposition. This fault comes to within 0.1 sec (75 m) of the ground surface. A shallow antithetic normal fault at STAT 390 displaces the Wilcox and Claiborne down to the west. The east-bounding fault of the deep graben at STAT 420 has 0.025 sec (40 m) of displacement at the top of the Cretaceous section, and there is no evidence that this fault displaces overlying Tertiary sediments.

Strata from the western end of the line to STAT 380 are gently easterly dipping to horizontal except adjacent to the structures discussed above. From STAT 380 to the eastern end of the line, strata dip westerly (opposite to the regional depositional dip). Thus, it appears that during post-Claiborne reactivation of the fault, at STAT 380 there was minor westward tilting of the hanging-wall block.

Line 5SG imaged the zone above the west-bounding fault of the deep graben of line 5 (Figs. 1 and 14). The strong reflector at 0.08 sec (50 m) in line 5SG (Fig. 14) is either the unconformity at the base of the Pliocene–Pleistocene section or the top of the Pliocene–Pleistocene gravels encountered in adjacent water wells. The Pliocene–Pleistocene strata at STAT 125 appear to be folded and faulted down to the east. Also at STAT 125, strong reflectors between 0.08 (56 m) and 0.06 sec (42 m) appear to be truncated. The truncation of reflectors and minor reverse separation across this fault suggest that it may be a transpressional strike-slip fault. A second fault is interpreted in line 5SG at STAT 230. This west-dipping reverse fault displaces Quaternary strata 0.005 sec (3.5 m) and can be traced to within 0.05 sec (35 m) of the ground surface.

Lines 7 and 7SG were acquired across the ridge margin north of line 5 to determine if faulting existed beneath the eastern ridge margin (Figs. 1, 15, and 16). Line 7 reveals that the top of the Cretaceous is 0.03 sec (37 m) higher under the ridge than to the east and that there is a flexure or west-dipping reverse fault at STAT 405. The overlying Wilcox is also higher under the ridge, but it is not possible to trace the fault at STAT 405 into the Wilcox. Folding within the Wilcox at STAT 415 may be related to the underlying fault or it may be syndepositional and related to channel scour within the Wilcox between STATs 425 and 450. The reverse fault at STAT 440 displaces the top of the Paleozoic 0.02 sec (25 m), but it does not displace overlying Cretaceous strata.

Line 7SG (Fig. 16) did not image the stratigraphy beneath Crowley's Ridge in the western half of the line; however, probable Eocene strata at depths of 0.03 to 0.06 sec (21 to 42 m) dip easterly off of Crowley's Ridge between STATs 185 and 138. The easterly dip could be depositional or a result of post-Eocene ridge uplift. Truncated reflectors and down-to-the-west folding of deeper Tertiary reflectors at STAT 140 does, however, support post-Eocene faulting.

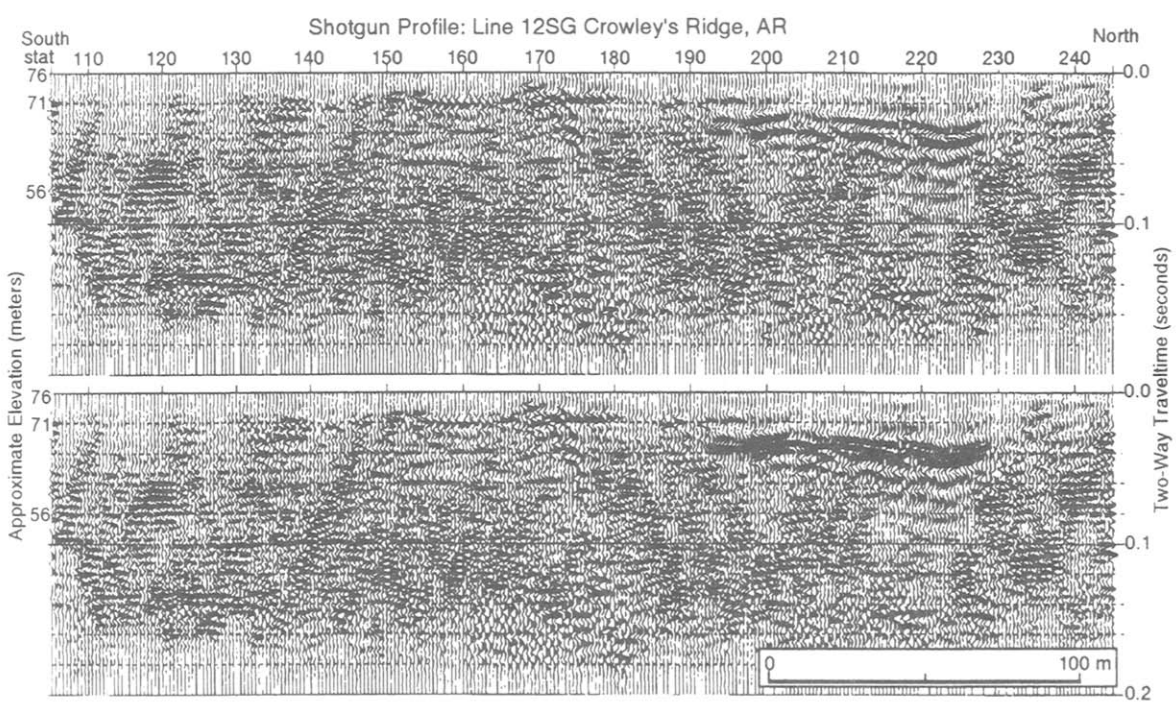

Figure 12. Shotgun reflection profile 12SG and geologic interpretation. See Figure 1 for location. This line is 351-m long and was shot from STAT 840 to 860 on Mini-Sosie line 12 (Fig. 11). The highlighted reflector is probably within Eocene strata.

Fault Zone beneath the Western Margin of the Northern Ridge Segment

Line 4 is a 1.5-km-long line located on the west side of the northern segment of Crowley's Ridge (Figs. 1 and 17). Topographic relief at this location is 20 m with three small ridges paralleling the margin of Crowley's Ridge.

All the reflectors dip gently to the east, with five faults apparently displacing the top of the Cretaceous and two of the five possibly displacing the base of the Wilcox. A normal fault at STAT 715 displaces the Cretaceous 0.06 sec (61 m) down to the west. Reflectors are displaced in the Midway Group, but the base of the Wilcox is not disrupted above this fault. At STAT 730, a second normal fault displaces the Cretaceous 0.015 sec (22 m) and basal Wilcox down to the west. A normal fault at STAT 755 also displaces the Cretaceous 0.02 sec (30 m) and basal Wilcox down to the west. A small, west-dipping normal fault at STAT 770 displaces the Cretaceous 0.01 sec (12.5 m). The fault at STAT 785 is a west-dipping fault with 0.01 sec (12.5 m) of reverse displacement. The net vertical separation across the entire fault zone is less than the sum of the fault displacements because the strata dip eastward.

There are two and perhaps three faulting events revealed in line 4. The down-to-the-west normal faulting at STAT 715 resulted in a thicker Midway section west of the fault, but activity ceased before Wilcox deposition. Normal faulting also occurred post lower Wilcox, as indicated by the displaced basal Wilcox at STATs 730 and 755. A possible compressional third faulting event is indicated by the small reverse fault at STAT 785, but timing of this event is indeterminable.

Line 8 is a 1.4-km-long line located north of line 4 (Figs. 1 and 18). Cretaceous strata is 0.05 sec (55 m) higher under Crowley's Ridge than at the western end of the line. Most of the structural relief is attributable to westerly tilted strata between STATs 500 and 520, but there is also displacement across four faults. All of the faults displace the top of the Cretaceous with the fault at STAT 560, apparently displacing Midway Group strata. All of these faults may displace Tertiary strata, but the absence of reflections in the Midway Group and the Wilcox Group does not allow this determination.

In both lines 4 and 8, the faulting is distributed over the entire lengths of the profiles. We postulate that the fault zone between STATs 710 and 775 of line 4 probably corresponds to the fault zone on line 8 because the east–west spacing of the faults is very similar on their respective lines.

Formation of Crowley's Ridge

We have interpreted seismic data to suggest that faults lie beneath five margins of Crowley's Ridge. However, it appears that most of the fault displacement (approximately 60 of 67 m) is Paleocene and Eocene in age, as reflected in

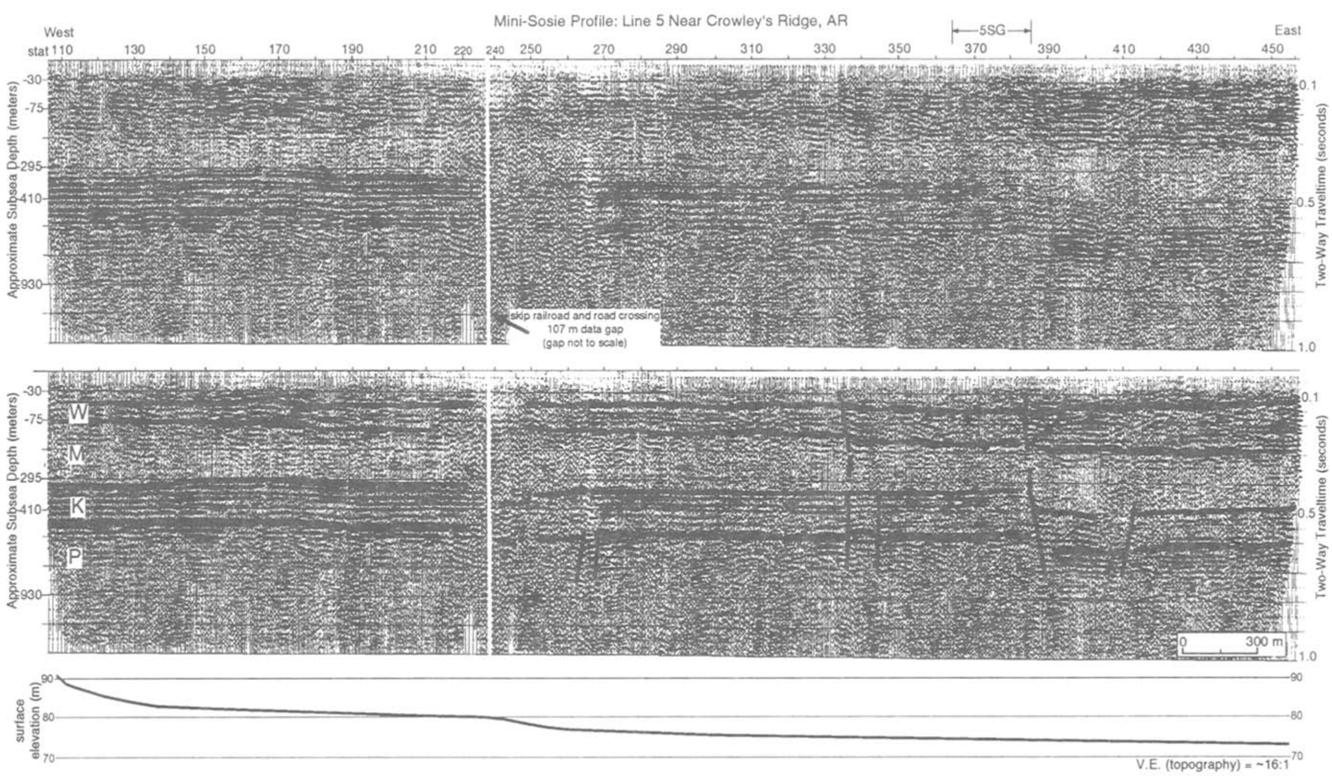

Figure 13. Mini-Sosie reflection line 5 and geologic interpretation. See Figure 1 for location. The line is 5.0-km long. P = Paleozoic, K = Cretaceous, M = Midway Group, and W = Wilcox Group.

the thickening of the Midway and Wilcox sections across faults. In addition, the near-surface strata imaged in the shotgun profiles have less than 8 m of fault displacement. From this faulting history, we must conclude that the topographic relief of Crowley's Ridge, which averages 60 m, is only in part attributable to faulting, and that most of the relief is due to Wisconsin incision of the ancestral Mississippi and ancestral Ohio rivers. At lines 1SG and possibly 12SG and 7SG, the faults displace near-surface strata, and thus there has been between 7.5 and 2 m of post-Eocene reactivation of these ridge-bounding faults. However, we believe this relatively minor reactivation may have strongly influenced the formation of Crowley's Ridge.

The distribution of Wisconsin-age terraces on either side of Crowley's Ridge suggests that the ridge and perhaps immediately adjacent area were rising during Wisconsin incision of the ancestral Mississippi and ancestral Ohio rivers (Fig. 19). The highest and oldest terrace surfaces are immediately adjacent to the ridge (Saucier and Snead, 1989; Royall *et al.,* 1991). The total width of the terraces on the eastern side of Crowley's Ridge is 60 km, and the late-Holocene flood plain of the Mississippi River is on the extreme eastern side of the Mississippi River valley. For the entire length of Crowley's Ridge, there is very little terrace preservation east of the Mississippi River. The Black River–White River drainage system flows along the eastern margin of the Ozark Plateau, but more importantly, it flows along the western margin of the 35- to 50-km-wide Wisconsin terraces of the ancestral Mississippi River (Fig. 19). The Black–White river system is an underfit river system that is flowing within the youngest valley of the ancestral Mississippi River. Like the Holocene Mississippi River, there is very little preservation of Pleistocene terraces on the western side of the ancestral Mississippi River (Holocene Black–White river system). We postulate that uplift of Crowley's Ridge (perhaps arching centered on Crowley's Ridge) and concurrent Mississippi valley denudation during Wisconsin time resulted in westward migration of the incising ancestral Mississippi River and eastern migration of the incising ancestral Ohio River.

Evolution of the confluence of the ancestral Mississippi River and the ancestral Ohio River may also have been tectonically influenced. The ancestral Mississippi and ancestral Ohio rivers at one time joined south of Crowley's Ridge (Fisk, 1944). Diversion of the ancestral Mississippi River through Crowley's Ridge at the Bell City–Oran gap (Fig. 19) occurred approximately 14,500 yr B.P. (Royall *et al.,* 1991). This diversion has been attributed to the catastrophic release of glacial meltwater and consequent overtopping of Crowley's Ridge (Royall *et al.,* 1991). A second diversion across Crowley's Ridge moved the course of the ancestral Mississippi River to its present location at Thebes Gap between 11,540 and 9050 yr B.P. This event has also been attributed to the catastrophic release of glacial meltwater

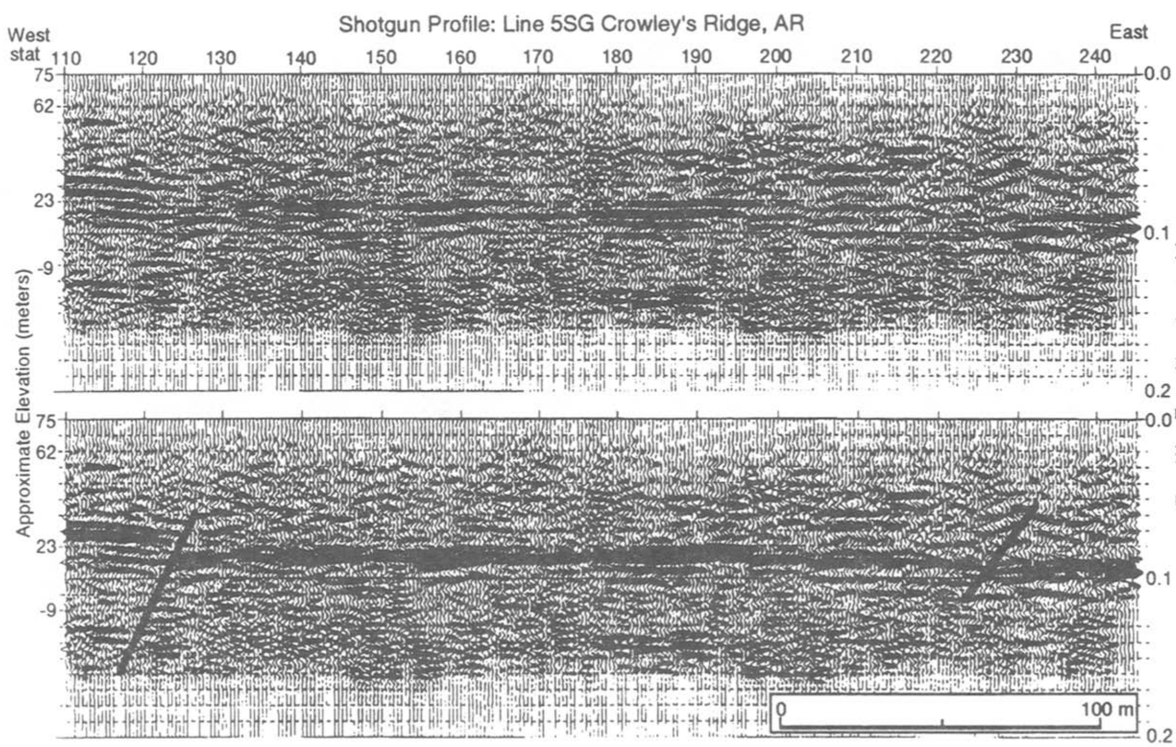

Figure 14. Shotgun reflection profile 5SG and geologic interpretation. This line is 329-m long and was shot from STAT 365 to 385 on Mini-Sosie line 5 (Fig. 13). The strong reflectors at 0.1 sec are probably gravels at the base of the Pliocene–Pleistocene section.

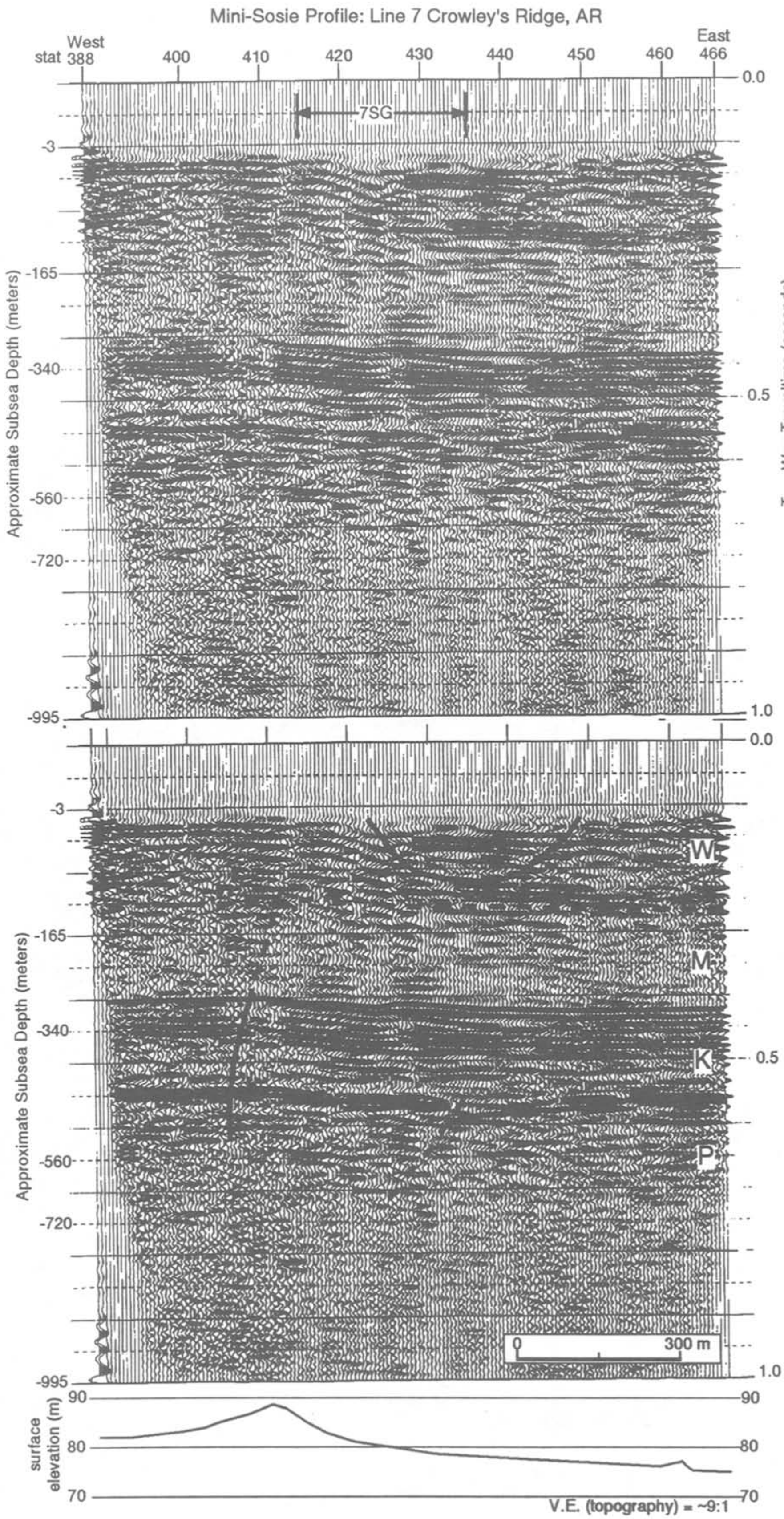

Figure 15. Mini-Sosie reflection line 7 and geologic interpretation. See Figure 1 for location. The line is 1.2-km long. P = Paleozoic, K = Cretaceous, M = Midway Group, and W = Wilcox Group.

(Royall *et al.,* 1991). Thus, during late Wisconsin time, the confluence of the Mississippi and Ohio rivers moved north. We speculate that this northward shifting of the confluence of the ancestral Mississippi and Ohio rivers may have been influenced by impeded southerly flow as a result of late-Wisconsin uplift of Crowley's Ridge (Fisk, 1944; Johnston, 1982).

Conclusions

A rather complex Tertiary structural history is revealed in the Mini-Sosie lines of Crowley's Ridge. Paleocene normal faulting is evident by the thickening of the Midway Group in line 4. Paleocene–Eocene normal faulting is also revealed by thickening of the Wilcox Group in line 5. Post-Wilcox (lower Eocene) normal faulting is evident in most of the lines. Post-Claiborne compression is evident in lines 2, 11, 1SG, 5, and 5SG.

The steepness of the faults, the normal and reverse fault movements occurring within a small area and over a relatively short length of time (Paleocene and Eocene), and the marked strike-slip appearance of the major faults in lines 2 and 11 suggest that most of these faults may be the upper portions of flower structures, as has been interpreted in other areas of the Mississippi embayment (Luzietti and Harding, 1991; Schweig *et al.,* 1992; Sexton *et al.,* 1992).

At line 1SG, fault displacement can be traced to within 20 m of the ground surface (Fig. 7). Thus, at this location we believe the ridge margin may be a fault scarp.

Lines 2 and 11 display a horst beneath the eastern margin of the ridge that has folded the Wilcox Group. At line 2, the Cretaceous and Tertiary sections are at the same elevation beneath the ridge and east of the ridge. However, line 11 reveals that the Cretaceous and Tertiary sections are higher beneath Crowley's Ridge. It appears that post-Eocene transpression has occurred beneath this margin. Since no shotgun data were collected across this margin, it is not possible to determine if there has been Quaternary fault reacti-

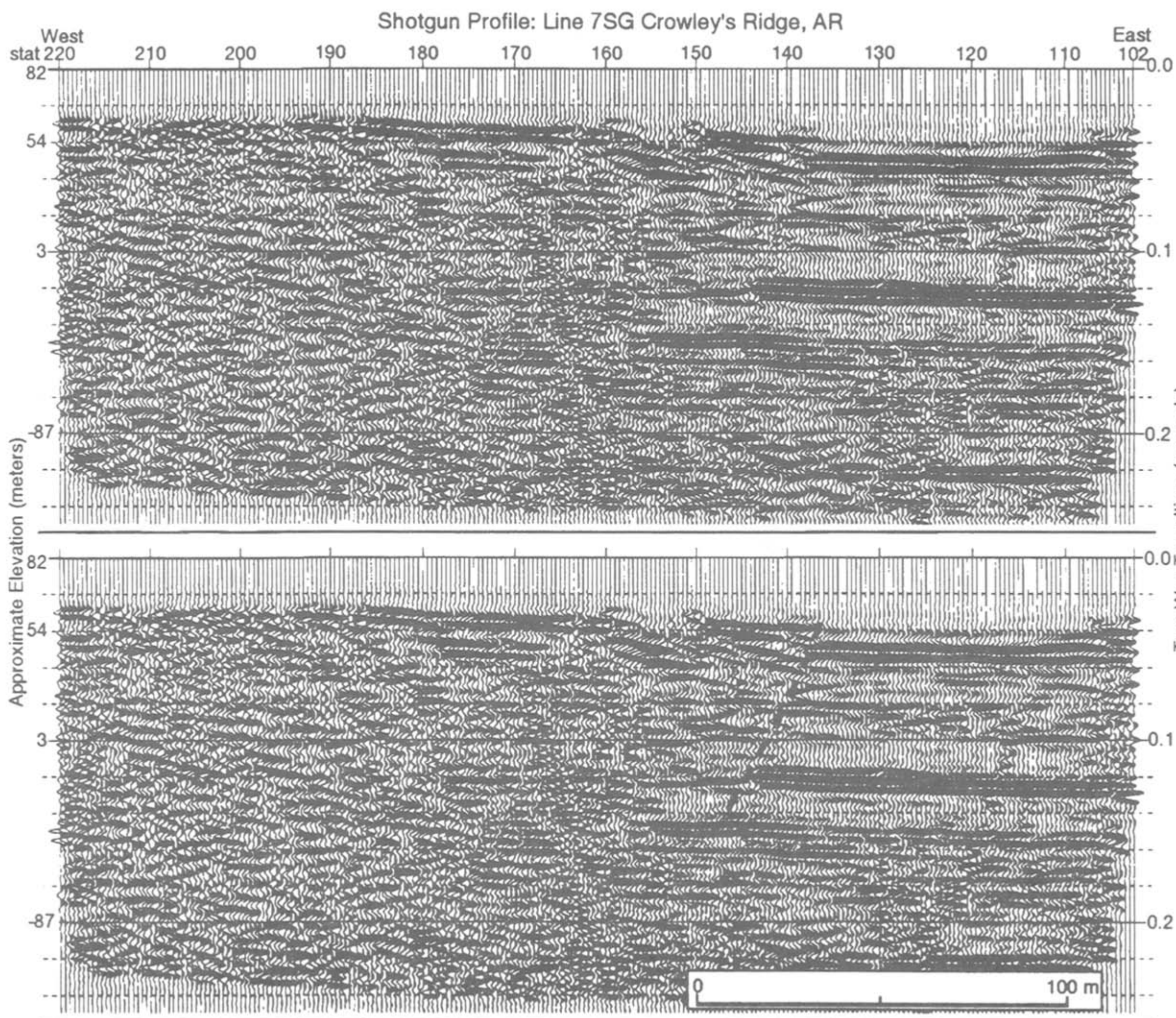

Figure 16. Shotgun reflection profile 7SG and geologic interpretation. This line is 288-m long and was shot from STAT 415 to 435 of Mini-Sosie line 7 (Fig. 15). The strong reflectors at 0.12 sec are probably within the Eocene section.

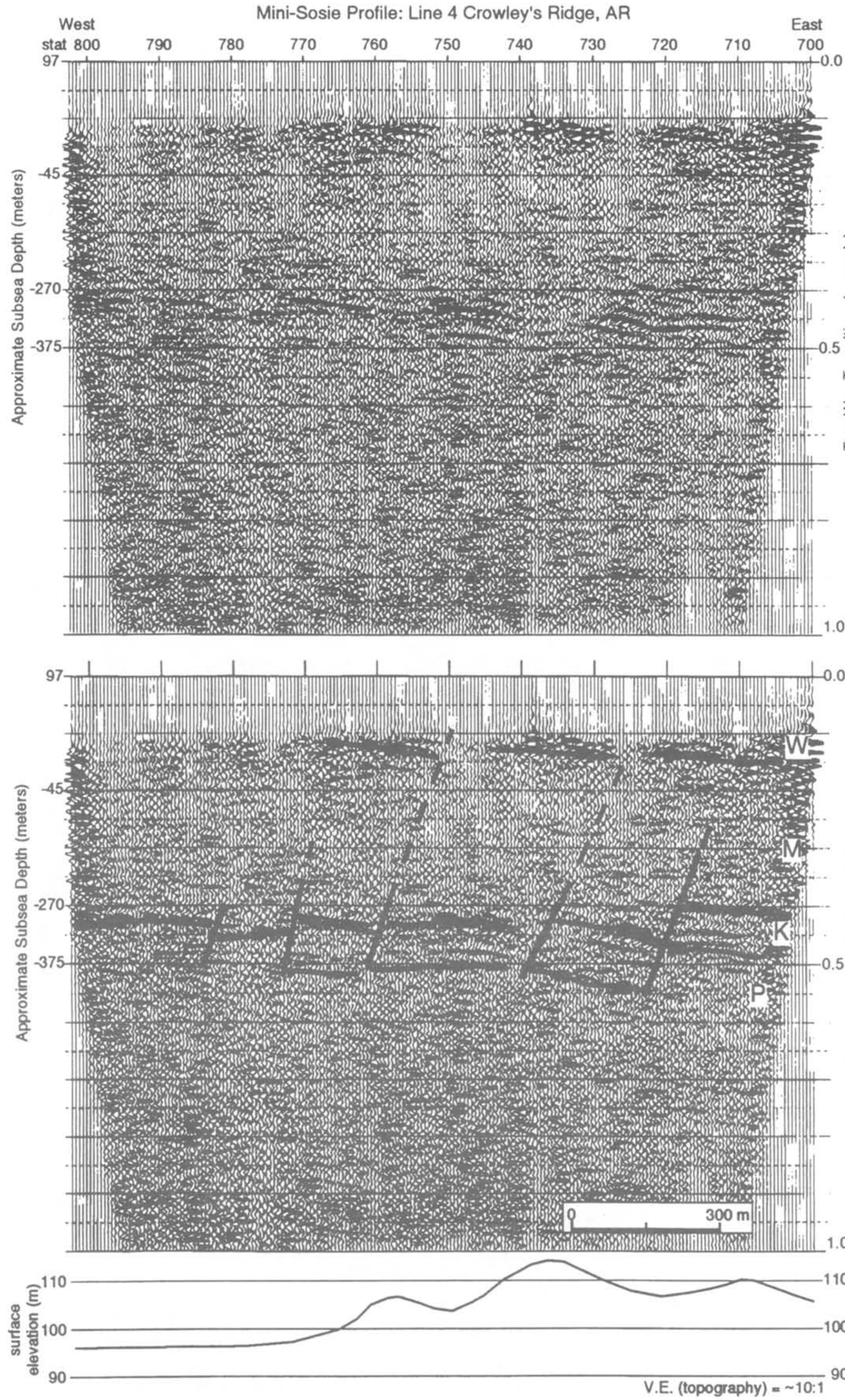

Figure 17. Mini-Sosie reflection line 4 and geologic interpretation. See Figure 1 for location. The line is 1.5-km long. P = Paleozoic, K = Cretaceous, M = Midway Group, and W = Wilcox Group.

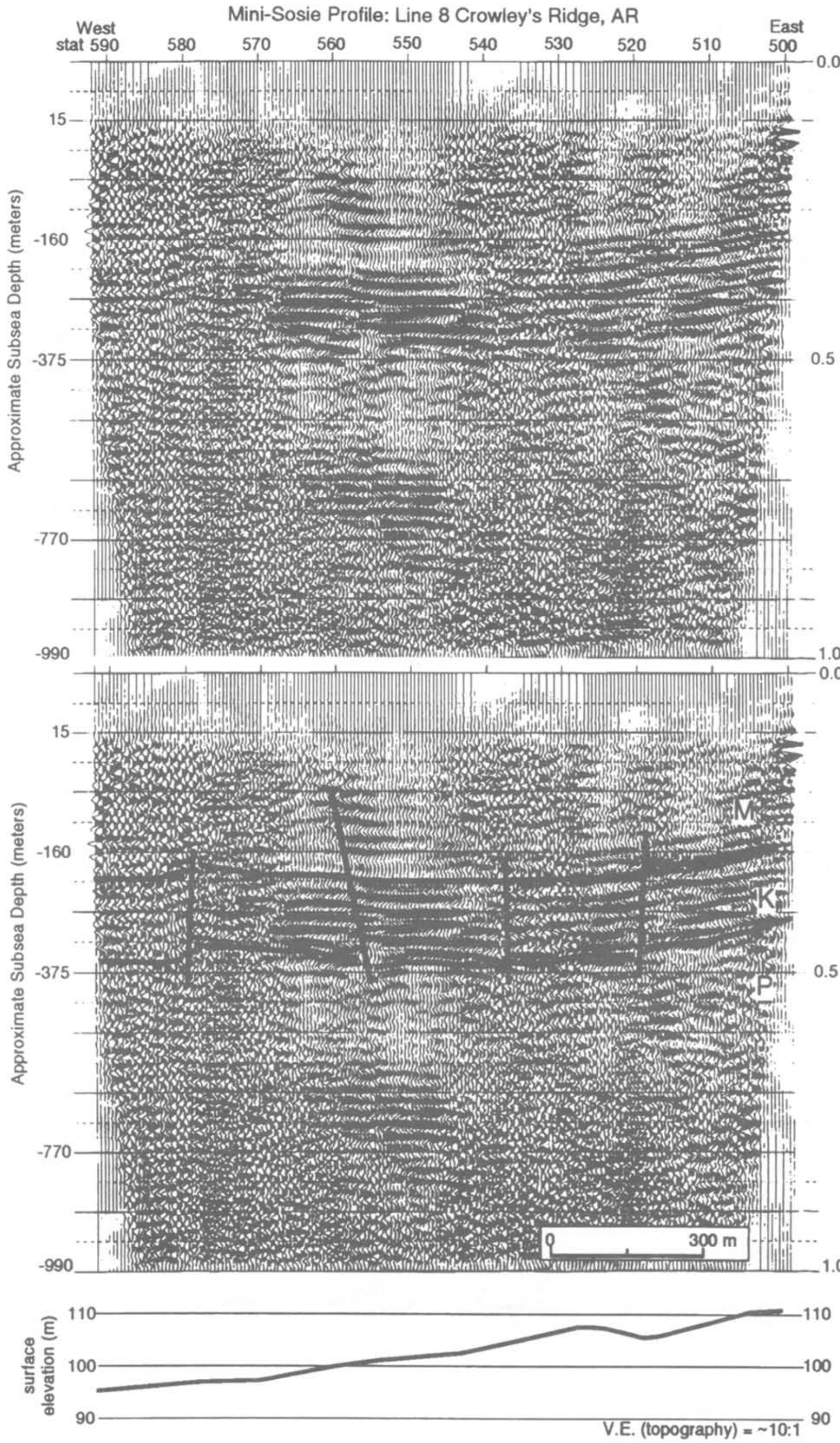

Figure 18. Mini-Sosie reflection line 8 and geologic interpretation. See Figure 1 for location. The line is 1.4-km long. P = Paleozoic, K = Cretaceous, and M = Midway Group.

vation, but the location of the horst structure directly below the ridge margin suggests Quaternary reactivation.

We believe the ridge margin at lines 3 and 12 (Fig. 1) is underlain by a down-to-the-southwest fault that has had post-Eocene reactivation. In the subsurface, a fault through this area appears to define the southwestern limit of artesian flow from the Upper Cretaceous Nacatoch sand (Boswell *et al.*, 1965), separates two areas of different crustal thickness (Mooney *et al.*, 1983), and the southeastern projection of the fault defines the southern limit of intense liquefaction in 1811–1812 and modern New Madrid seismicity near Marked Tree, Arkansas (Cox, 1988a, b).

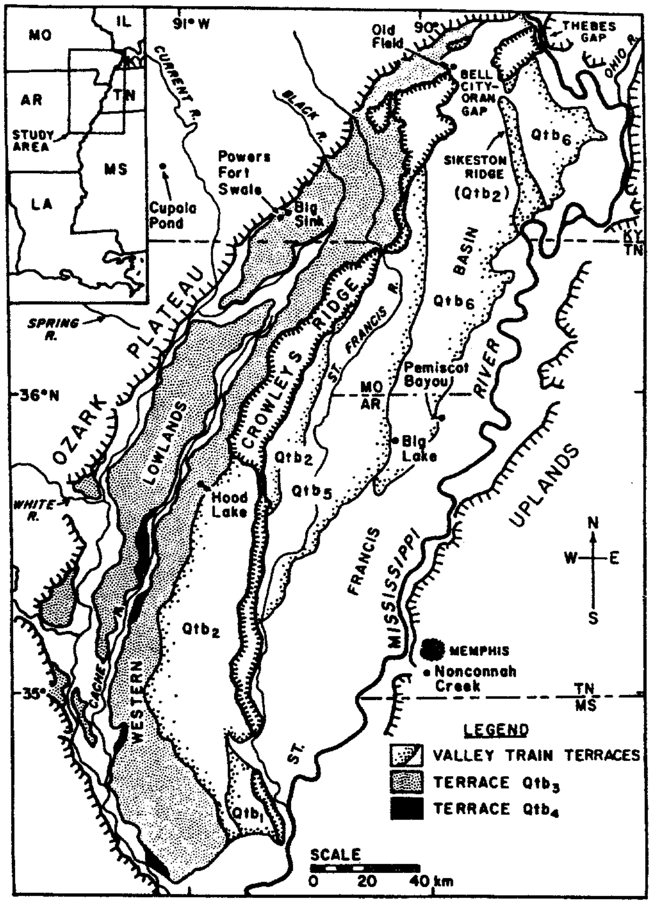

Figure 19. Quaternary geomorphic surfaces within and adjacent to the central Mississippi alluvial valley. Four braided-stream terraces are mapped within the Western Lowlands: Qtb_1 of late Illinoian Age, Qtb_2 of early to middle Wisconsinan Age, and Qtb_3 and Qtb_4 of late Wisconsinan Age. The Cache River terrace (Qtc) of late Wisconsinan/early Holocene Age (?) is not shown at this scale. Three braided-stream terraces are mapped within the St. Francis Basin of the Eastern Lowlands: Qtb_2 of early to middle Wisconsinan Age and Qtb_5 and Qtb_6 of late Wisconsinan/early Holocene Age. Terrace Qtb_3 is mapped using the dense stippled pattern, terrace Qtb_4 is mapped using black, and all other braided-stream terraces are shown using a light stippled pattern for valley train terraces (from Royall *et al.*, 1991). Evident in this map are the broad terraces on either side of Crowley's Ridge with the modern Mississippi River on the extreme eastern side of the Mississippi Valley and the Black–White river system (location of the ancestral Mississippi River) on the extreme western side of the Mississippi valley.

The ridge margin at line 7 is underlain by a down-to-the-east fault and/or flexure that may have had post-Eocene reactivation, and we also believe a fault underlies the ridge margin in line 5 (Figs. 1, 15, 16, and 13). Post-Claiborne folding is well expressed in line 5, in addition to post-Wilcox movement on a large graben at the eastern end of the line. This graben is within the western margin of the Reelfoot rift (Fig. 1) and has had Tertiary and Quaternary (line 5SG of Fig. 14) fault reactivation. These observations, in conjunction with the very high strain rate recently documented for this rift margin by Liu *et al.* (1992), suggest that this rift margin may be capable of generating earthquakes.

Lines 4 and 8 reveal a number of faults beneath the ridge margin (Figs. 1, 17, and 18). Faults can be correlated from line 4 to line 8, thus indicating that the faults parallel the ridge margin and that this margin is probably fault controlled. No shotgun lines were collected across this ridge margin, and so it is not possible to determine if there has been Quaternary movement on these faults. However, the coincidence of subsurface faults with surface topography illustrated in line 4 (Fig. 17) does suggest Quaternary fault reactivation.

Focal mechanisms along the southern arm of New Madrid seismicity (Fig. 3) reveal right-lateral strike-slip faulting within the Blytheville arch (Herrmann and Canas, 1978; Stauder, 1982). Reverse faulting is recorded in the northwest-trending zone of seismicity within the Pascola arch and right-lateral faulting is predominant in the zone of seismicity that trends northeast from near New Madrid, Missouri (Chiu *et al.*, 1992). Like the New Madrid seismic zone, we believe that the bounding faults of the northern and southern segments of Crowley's Ridge may be right-lateral strike-slip faults and that the bend at Jonesboro may be a left-stepping bend, perhaps with an underlying reverse fault (Van Arsdale *et al.*, 1994).

The Mini-Sosie lines reveal that much of the faulting beneath Crowley's Ridge is Paleocene and Eocene in age with shotgun lines and geomorphic evidence suggesting reactivation in late-Wisconsin time. Thus, we believe that Crowley's Ridge was probably seismically active during the Wisconsin but now seismicity has shifted to the New Madrid seismic zone. Although most of the faulting of Crowley's Ridge and the west-bounding fault of the Reelfoot rift appear to be Tertiary and Wisconsin in age, it is important to note that some of the faults may cut the entire Quaternary section (lines 1SG and 5SG in particular) and that the faults bounding the ridge and the rift are favorably oriented for strike-slip and reverse movement in the current midcontinent stress field (Zoback and Zoback, 1989; Liu *et al.*, 1992).

Acknowledgments

The contents of this article were developed under a grant from the Department of the Interior, U.S. Geological Survey (USGS) (14-08-0001-G1925). However, those contents do not necessarily represent the policy of the USGS, and you should not assume endorsement by the federal government. The project could not have been accomplished without the dedicated work of the U.S. Geological Survey's Mini-Sosie crew and students from the University of Memphis and the University of Arkansas. CERI Contribution Number 245.

References

Autin, W. J., S. F. Burns, B. J. Miller, R. T. Saucier, and J. I. Snead (1991). Quaternary geology of the Lower Mississippi Valley, in *Quaternary Nonglacial Geology: Conterminous U.S.: The Geology of North America, Volume K-2,* edited by R. B. Morrison, 547–582.

Barbier, M. G., P. Bondon, R. Mellinger, and J. R. Viallix (1976). Mini-Sosie for shallow land seismology, *Geophys. Prospect.* **24,** 518–527.

Boswell, E. H., G. K. Moore, L. M. MacCary, and others (1965). Cretaceous aquifers in the Mississippi embayment, *U.S. Geol. Surv. Profess. Pap. 448-C.*

Call, R. E. (1891). The geology of Crowley's Ridge, Annual report of the Geological Survey of Arkansas.

Chiu, J. M., A. C. Johnston, and Y. T. Yang (1992). Imaging the active faults of the central New Madrid seismic zone using PANDA array data, *Seism. Res. Lett.* **63,** no. 3, 375–393.

Cox, R. T. (1988a). Evidence of Quaternary ground tilting associated with the Reelfoot Rift zone, northeast Arkansas, *Southeastern Geol.* **28,** no. 4, 211–224.

Cox, R. T. (1988b). Evidence of Late Cenozoic activity along the Bolivar-Mansfield tectonic zone, midcontinent, U.S.A., *Compass* **4,** no. 2, 207–213.

Crone, A. J. (1981). Sample description and stratigraphic correlation of the New Madrid test well-1-W, New Madrid County, Missouri, *U.S. Geol. Surv. Open-File Rept. 81-426.*

Dart, R. L. (1990). Catalog of drill-hole data from wells in the Paleozoic rocks of the Upper Mississippi Embayment, *U.S. Geol. Surv. Open-File Rept. 90-260.*

Ervin, C. P., and L. D. McGinnis (1975). Reelfoot rift: reactivated precursor to the Mississippi embayment, *Geol. Soc. Am. Bull.* **86,** 1287–1295.

Fischer, K. J., and S. A. Schumm (1993). Geomorphic evidence of deformation in the northern part of the New Madrid seismic zone (abstract), *Geol. Soc. Am.* **25,** no. 3, 19.

Fisk, H. N. (1944). Geologic investigation of the alluvial valley of the lower Mississippi River, U.S. Army Corps of Engineers, Vicksburg, Mississippi.

Frederiksen, N. O., L. M. Bybell, R. A. Christopher, A. J. Crone, L. E. Edwards, T. G. Gibson, J. E. Hazel, J. E., Repetski, D. P. Russ, C. C. Smith, and L. W. Ward (1982). Biostratigraphy and paleoecology of lower Paleozoic, upper Cretaceous, and lower Tertiary rocks in U.S. Geological Survey New Madrid test wells, southeastern Missouri, *Tulane Studies Geol. Paleontol.* **17,** no. 2, 23–45.

Guccione, M. J., W. L. Prior, and E. M. Rutledge (1986). *The Tertiary and Quaternary Geology of Crowley's Ridge; a Guidebook,* Arkansas Geologic Commission. Little Rock, AR.

Guccione, M. J., R. H. Lafferty, and L. S. Cummings (1988). Environmental constraints of human settlement in an evolving Holocene alluvial system, the lower Mississippi valley, *Geoarchaeology* **3,** no. 1, 65–84.

Guccione, M. J., W. L. Prior, and E. M. Rutledge (1990). The Tertiary and early Quaternary geology of Crowley's Ridge, in *Field Guide to the Mississippi Alluvial Valley Northeast Arkansas and Southeast Missouri,* M. Guccione and E. Rutledge (Editors), Friends of the Pleistocene South-Central Cell, Fayetteville, AR 23–44.

Hamilton, R. R. and M. D. Zoback (1982). Tectonic features of the New Madrid seismic zone from seismic reflection profiles, in *Investigations of the New Madrid, Missouri, Earthquake Region,* F. Mc Keown and L. Pakiser (Editors), *U.S. Geol. Surv. Profess. Pap. 1236-F,* 54–82.

Hamilton, R. M. and F. A. McKeown (1988). Structure of the Blytheville arch in the New Madrid seismic zone, *Seism. Res. Lett.* **59,** 117–121.

Herrmann, R. B. and J. A. Canas (1978). Focal mechanism studies in the New Madrid seismic zone, *Bull. Seism. Soc. Am.* **68,** 1095–1102.

Hildenbrand, T. G. (1985). Rift structure of the northern Mississippi embayment from the analysis of gravity and magnetic data, *J. Geophys. Res.* **90,** 12607–12622.

Holbrook, D. F. (1980). Arkansas lignite investigations—preliminary report, Arkansas Geological Commission. Little Rock, AR.

Howe, J. R. and T. L. Thompson (1984). Tectonics, sedimentation, and hydrocarbon potential of the Reelfoot rift, *Oil Gas J.* **82,** 179–190.

Howe, J. R. (1985). Tectonics, sedimentation, and hydrocarbon potential of the Reelfoot aulacogen, *Master's Thesis,* University of Oklahoma, Norman.

Johnston, A. C. (1982). A major earthquake zone on the Mississippi, *Sci. Am.* **246,** no. 4, 60–68.

Liu, L., M. D. Zoback, and P. Segall (1992). Rapid intraplate strain accumulation in the New Madrid seismic zone, *Science* **257,** 1666–1669.

Luzietti, E. A. and S. T. Harding (1991). Reconnaissance seismic reflection surveys in the New Madrid seismic zone, northeast Arkansas and southeast Missouri, U.S. Geol. Surv. Misc. Field Studies Map MF-2135.

Luzietti, E. A., L. R. Kanter, E. S., Schweig, K. M. Shedlock, and R. B. Van Arsdale (1992). Shallow deformation along the Crittenden County fault zone near the southeast margin of the Reelfoot rift, northeastern Arkansas, *Seism. Res. Lett.* **63,** no. 3, 263–275.

Mayne, H. W. (1962). Common reflection point horizontal data stacking techniques, *Geophysics* **27,** 952–965.

Meissner, C. R. (1984). Stratigraphic framework and distribution of lignite on Crowley's Ridge, Arkansas, Arkansas Geologic Commission Information Circular 28-B. Little Rock, Arkansas.

Mooney, W. D., M. C. Andrews, A. Ginzburg, D. A. Peters, and R. M. Hamilton (1983). Crustal structure of the northern Mississippi embayment and a comparison with other continental rift zones, *Tectonophysics* **94,** 327–348.

Moore, G. K., and D. L. Brown (1969). Stratigraphy of the Fort Pillow test well, Lauderdale County, Tennessee, Tennessee Division of Geology, Report of Investigations 26.

Murray, G. E. (1961). *Geology of the Atlantic and Gulf Coastal Province of North America,* Harper and Brothers, New York.

Nelson, K. D. and J. Zhang (1991). A COCORP deep reflection profile across the buried Reelfoot rift, southcentral United States, *Tectonophysics* **197,** no. 2-4, 271–293.

Nelson, W. J. and R. W. Harrison (1993). Post-Cretaceous faulting at head of Mississippi embayment (abstract), *Geol. Soc. Am.* **25,** no. 3, 69–70.

Renfroe, C. A. (1949). Petroleum exploration in eastern Arkansas with selected well logs, Arkansas Resource and Development Commission, Division of Geology Bulletin 14.

Royall, P. D., P. A. Delcourt, and H. R. Delcourt (1991). Late Quaternary paleoećology and paleoenvironments of the central Mississippi alluvial valley, *Geol. Soc. Am. Bull.* **103,** no. 2, 157–170.

Russ, D. P. (1982). Style and significance of surface deformation in the vicinity of New Madrid, Missouri, in *Investigations of the New Madrid, Missouri, Earthquake Region,* F. McKeown and L. Pakiser (Editors), *U.S. Geol. Surv. Profess. Pap. 1236-H,* 95–114.

Rutledge, E. M., L. T. West, and M. J. Guccione (1990). Loess deposits of northeast Arkansas, in *Field Guide to the Mississippi Alluvial Valley—Northeast Arkansas and Southeast Missouri,* M. Guccione and E. Rutledge (Editors), Friends of the Pleistocene South-Central Cell, 57–98.

Saucier, R. T. (1974). Quaternary geology of the lower Mississippi valley, *Arkansas Archaeological Survey Research Series 6.*

Saucier, R. T. and J. I. Snead (1989). Quaternary geology of the lower Mississippi valley, Louisiana Geological Survey Map, 1:1,000,000.

Schweig, E. S., F. Shen, L. R. Kanter, E. A. Luzietti, R. B. Van Arsdale, K. M. Shedlock, and K. W. King (1992). Shallow seismic reflection survey of the Bootheel lineament area, southeastern Missouri, *Seism. Res. Lett.* **63,** no. 3, 285–295.

Sexton, J. L., H. Henson, P. Dial, and K. M. Shedlock (1992). Mini-Sosie high resolution seismic reflection profiles along the Bootheel lineament in the New Madrid seismic zone, *Seism. Res. Lett.* **63,** no. 3, 297–307.

Stauder, W. (1982). Present-day seismicity and identification of active faults in the New Madrid seismic zone, in *Investigations of the New Madrid, Missouri, Earthquake Region,* F. McKeown and L. Pakiser (Editors), *U.S. Geol. Surv. Profess. Pap. 1236,* 21–30.

Stearns, R. G. (1957). Cretaceous, Paleocene, and lower Eocene geologic history of the northern Mississippi embayment, *Geol. Soc. Am. Bull.* **68,** 1077–1100.

Van Arsdale, R. B., E. S. Schweig, L. R. Kanter, R. A. Williams, K. M. Shedlock, and K. W. King (1992). Preliminary shallow seismic reflection survey of Crowley's Ridge, northeast Arkansas, *Seism. Res. Lett.* **63,** no. 3, 309–320.

Van Arsdale, R. B., R. A. Williams, E. S. Schweig, K. M. Shedlock, L. R. Kanter, and K. W. King (1994). Preliminary seismic reflection study of Crowley's Ridge, northeast Arkansas, *U.S. Geol. Surv. Profess. Pap. 1538 C,* C1–C16.

Zoback, M. L. and M. D. Zoback (1989). Tectonic stress field of the continental United States, *Geophysical Framework of the Continental United States,* L. Pakiser and W. Mooney (Editors), *Geol. Soc. Am. Memoir* **172,** 523–540.

Department of Geological Sciences
University of Memphis
Memphis, Tennessee 38152
(R.B.V.A.)

Branch of Earthquake and Landslide Hazards
U.S. Geological Survey
Denver, Colorado 80225
(R.A.W., K.M.S., J.K.O., K.W.K.)

United States Geological Survey—CERI
University of Memphis
Memphis, Tennessee 38152
(E.S.S.)

Manuscript received 2 June 1994.